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FEATURES

Investigation of the Physical Properties of
Certain Chromium-Aluminum Steels

—*Frank B. Lounsberry and
Walter R. Breeler* 733

Progress Made in the Use of Electric

Furnaces for Heat Treating —*A. N. Otis* 767

High Chromium Steels —*Owen K. Parmiter* 796

Application of Science to the Steel Industry—

Section III —*Dr. W. H. Hatfield* 817

Constitution of Steel and Cast Iron

Section II—Part VIII —*F. T. Sisco* 837

Refractories and Heat Insulation in Connection

with Furnace Design —*Guy A. Barker* 851



Vol. XV No. 5
May, 1929

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NO. 5

AN INVESTIGATION OF THE PHYSICAL PROPERTIES OF CERTAIN CHROMIUM-ALUMINUM STEELS

BY FRANK B. LOUNSBERRY AND WALTER R. BREELER

Abstract

The following report pertains to a general investigation of the physical properties of steels, containing as main alloying constituents, aluminum from about 2 to 6 per cent and chromium from about 7 to 13 per cent, with silicon and carbon varying up to approximately 1 per cent maximum. Data is also included on the effect of adding small amounts of additional alloying elements, such as nickel, cobalt, molybdenum, vanadium, manganese, tungsten and copper.

The physical properties investigated were, 1. effect of thermal treatment on hardness and microstructure, 2. resistance to oxidation at elevated temperatures, 3. resistance to atmospheric corrosion, 4. forgeability, 5. tensile strength at normal and elevated temperatures, 6. impact values.

It was found that aluminum effectively stabilized the alpha iron phase and when in combination with chromium, greatly increased the resistance of the metal to oxidation at elevated temperatures.

THE use and effect of aluminum as an alloying addition to carbonless iron or plain carbon steels has been ably reported by such eminent investigators as Hadfield, Gwyer, Guillet, and others. The effect of small percentages of aluminum in stainless steels has been reported by Monypenny. The findings of these in-

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investigators as they concern the present research are briefly summarized in the appendix.

More recently, considerable data has been published on the so-called nitrogenizing steels containing various low percentage combinations of chromium, aluminum, nickel, molybdenum, etc. However, with the exception of that data on stainless and nitrogenizing steels, which is usually concerned with aluminum under 2 per cent, to our knowledge, very little published information is available pertaining to chromium steels of higher aluminum percentages. Wishing to learn more about such alloy combinations, it was decided to investigate in a general way and using only those means readily at hand, the nature and various properties of steels containing as main constituents, aluminum from about 2 to 6 per cent and chromium from about 7 to 13 per cent with silicon and carbon varying up to approximately 1 per cent maximum. In addition, it was also decided to determine in the same manner, the effect of adding to the above chromium, aluminum compositions, such alloys as nickel, cobalt, molybdenum, vanadium, manganese, tungsten and copper.

METHOD OF MANUFACTURE

The facilities at hand were not entirely suitable for the preparation of a high grade product as ordinarily considered from a laboratory standpoint. Nevertheless, a product was made which subsequently proved to be of entirely sufficient quality for the purpose. Any unfavorable conditions or practices have been noted.

In detail, the method of manufacture of the majority of the steels, consisted in melting iron punchings and alloys, excepting aluminum, in a 35-pound, acid, double arc, hand-operated electric furnace. Holding the slag back as much as possible, the liquid steel was poured into a torch-heated crucible containing a calculated amount of molten aluminum under a borax slag. After a quick thorough mixing, the resultant molten metal was cast into the form of tapered ingots, $3\frac{3}{4}$ inches square at the top and weighing about 32 pounds. It was early noticed that a reaction occurred between the aluminum and any acid slag with which it came in contact, forming a pasty undesirable mixture of alumina, slag and metal. It was only through careful manipulation that the amount of alumina inclusions in the steel was minimized. Microscopic examination of the finished bars revealed the presence of some in-

clusions in every bar made, but the average amount was surprisingly small and not sufficient to account for any exceptionally inferior forging or physical properties. The use of borax as a slag for the aluminum may be open to objection, but as far as could be determined, no detrimental properties were imparted to the steel by its use under the particular conditions mentioned. Boron determinations were made on several of the bars and varied from nil to 0.02 per cent. Neither salt nor cryolite slags could be used with the facilities at hand.

The second method of importance was that used in the manufacture of steels 5 to 11 inclusive, and consisted in melting iron punchings and other alloys, excepting aluminum, in the same manner as stated above. After removing a considerable quantity of the slag, preheated ferroaluminum was added in the furnace and mixed thoroughly with the molten steel. As soon as complete solution resulted, the heat was tapped. The ferroaluminum itself was made by the first method mentioned and analyzed approximately 50 per cent aluminum. This ferro alloy was hard, brittle, of smooth surface, and did not disintegrate on standing in air. Adding ferroaluminum in the acid furnace gave considerable difficulty especially when attempting to make a high aluminum content steel of approximately 5 to 6 per cent. The amount of ferro alloy necessary was quite voluminous and conditions in the furnace were very favorable to a reaction between the aluminum and acid slag. Both these factors resulted in a lowering of the bath temperature, which while desirable in itself had the disadvantage of entrapping appreciable alumina within the metal.

Considering the above two methods as they affected the finished bar, it was noted that with the exception of microstructure and grain size, the quality was about the same. The microstructure, however, of certain steels of permissible analysis, and grain size, were affected by the low pouring temperature usually resulting from the ferroaluminum method in contradistinction to the high pouring temperature produced by the crucible mixing method first mentioned. With steels which are not essentially ferritic due to a high chromium, aluminum, silicon and low carbon or nickel content, a low pouring temperature tends to produce a dendritic structure of ferrite and sorbite of fairly fine grain. With steels not essentially pearlitic due to a low aluminum, chrom-

Table I
Chemical Analysis of Steels Investigated

Type	Group	Steel	No.	No.	C	Mn	Si	Per Cent	Cr	Al	Ni	Cu	V	W	Co	Mo
Chrome	1	14	0.51	0.30	0.80	7.41	....	....	....	....	....	....	....	....	....	....
Cr-Si	2	12	0.41	0.40	3.62	8.76	....	....	....	....	....	....	....	....	....	....
Aluminum	3	59	0.47	0.40	3.15	8.37	....	....	....	....	....	....	....	....	....	....
		67	0.47	0.37	0.27	0.73	2.12	....	....	....	....	....	....	....	....	....
		68	0.32	0.33	0.24	0.17	2.44	....	....	....	....	....	....	....	....	....
		69	0.20	0.28	0.28	0.13	3.39	....	....	....	....	....	....	....	....	....
		17	0.22	0.40	1.00	....	3.6	....	....	....	....	....	....	....	....	....
		18	0.58	0.44	0.80	0.24	4.2	....	....	....	....	....	....	....	....	....
Al-Cr	4	1	0.39	0.40	0.95	7.9	2.47	....	....	....	....	....	....	....	....	....
		5	0.46	0.28	0.85	7.73	3.66	....	....	....	....	....	....	....	....	....
		9	0.37	0.40	1.10	8.62	3.81	....	....	....	....	....	....	....	....	....
		7	0.38	0.33	0.77	7.75	3.90	....	....	....	....	....	....	....	....	....
		8	0.62	0.34	1.1	8.6	3.90	....	....	....	....	....	....	....	....	....
		10	0.37	0.33	1.08	8.29	4.60	....	....	....	....	....	....	....	....	....
		28	1.08	0.44	0.85	12.18	4.96	....	....	....	....	....	....	....	....	....
		11	0.67	0.41	1.10	8.59	5.30	....	....	....	....	....	....	....	....	....
Al-Cr-Low Si	5	49	0.80	0.45	0.83	12.76	5.38	....	....	....	....	....	....	....	....	....
		43	0.47	0.42	0.23	9.46	4.38	....	....	....	....	....	....	....	....	....
		44	0.32	0.30	0.17	9.74	4.81	....	....	....	....	....	....	....	....	....
		38	0.14	0.29	0.21	8.74	5.14	....	....	....	....	....	....	....	....	....
Al-Cr-Mn	6	39	0.42	0.29	0.22	8.83	5.14	....	....	....	....	....	....	....	....	....
		15	0.52	0.92	0.90	8.91	5.24	....	....	....	....	....	....	....	....	....
Cu		26	0.45	1.45	0.88	8.39	5.00	....	....	....	....	....	....	....	....	....
		33	0.56	1.81	0.95	8.81	4.71	....	....	1.04	....	....	....	....	....	....
		30	0.50	2.54	0.93	9.16	5.25	....	....	....	....	....	....	....	....	....
Al-Cr-W	7	21	0.49	0.38	0.80	8.61	5.49	0.20	....	....	....	....	0.84	....	....	....
		20	0.48	0.30	0.75	8.24	5.39	....	....	....	....	....	1.31	....	....	....
Cu		37	0.48	0.61	0.89	9.37	5.05	....	....	1.26	....	....	1.55	....	....	....
		19	0.44	0.28	0.80	7.93	5.20	....	....	....	....	....	3.00	....	....	....
Al-Cr-Mo	8	16	0.48	0.31	0.90	8.24	4.6	....	....	....	....	....	....	....	....	0.39
Al-Cr-Co	9	27	0.39	0.20	0.74	8.66	5.13	....	....	....	....	....	....	2.93	....	....
Al-Cr-Ni	10	50	0.52	0.41	0.80	10.11	5.43	0.16	....	....	....	....	....	....	....	....
		51	0.42	0.34	0.72	8.87	4.81	0.31	....	....	....	....	....	....	....	....
		46	0.42	0.30	0.73	9.20	5.41	1.87	....	....	....	....	....	....	....	....
		23	0.42	0.26	0.95	7.7	5.0	3.63	....	....	....	....	....	....	....	....
		24	0.50	0.34	0.82	8.93	5.24	5.24	....	....	....	....	....	....	....	....
		3	0.53	0.40	0.73	8.59	5.14	6.62	....	....	....	....	....	....	....	....
Al-Cr-Ni-V	11	29	0.45	0.52	0.95	10.07	4.56	2.16	....	....	0.14	....	....	....	....	....
		47	0.50	0.53	0.87	10.26	5.38	2.01	....	....	0.52	....	....	....	....	....
		25	0.52	0.29	0.92	8.83	6.05	2.04	....	....	0.92	....	....	....	....	....
		54	0.50	0.30	0.78	9.50	5.47	2.15	....	....	1.02	....	....	....	....	....
		53	0.51	0.30	0.74	9.70	5.41	2.30	0.21	....	1.10	....	....	....	....	....
		52	0.46	0.31	0.90	9.43	5.32	2.71	....	....	1.07	....	....	....	....	....
		57	0.64	0.32	0.92	9.32	5.51	2.75	....	....	1.06	....	....	....	....	....
		58	0.58	0.43	1.19	8.73	5.13	2.78	....	....	1.09	....	....	....	....	....
		66	0.60	0.34	1.03	10.00	4.91	3.35	....	....	2.13	....	....	....	....	....
Al-Cr-Ni-W	12	60	0.54	0.34	0.83	9.79	5.45	2.76	....	....	....	....	2.18	....	....	....
		64	0.57	0.31	0.89	10.00	5.19	2.69	....	....	....	....	3.10	....	....	....
		65	0.59	0.30	1.02	8.98	4.95	2.8	....	....	0.16	4.20	....	....	....	....
		61	0.70	0.34	1.03	10.33	5.13	2.86	....	....	....	4.91	....	....	....	....
Al-Cr-Ni-Cu	13	34	0.48	0.55	0.87	8.62	5.19	1.11	1.15	....	....	....	....	....	....	....
		2	0.42	0.30	0.44	7.61	3.53	2.98	1.11	....	....	....	....	....	....	....
		62	0.64	0.41	0.96	9.37	4.61	3.16	1.14	....	....	....	....	....	....	....
		63	0.50	0.29	0.89	8.93	4.62	3.13	1.07	....	....	....	....	....	....	....
		4	0.46	0.45	0.86	8.79	3.97	3.32	1.10	....	....	....	....	....	....	....
Al-Cr-Ni-Cu-V																
	14	56	0.53	0.42	0.88	9.98	5.30	2.48	1.04	1.17	....	....	....	....	....	....
Al-Cr-Cu	15	31	0.52	0.38	0.89	8.45	4.40	....	1.15	....	....	....	....	....	....	....
		55	0.44	0.27	0.71	9.58	5.28	0.23	0.98	....	....	....	....	....	....	....
V		32	0.44	0.37	0.97	8.70	4.64	....	1.12	0.61	....	....	....	....	....	....
Mo		35	0.43	0.47	0.87	8.47	4.45	....	1.04	....	....	....	....	....	....	0.90
Co		36	0.44	0.25	0.88	8.99	5.3	....	1.22	....	....	....	....	2.89	....	....
Al-Cr-V	16	40	0.47	0.39	0.33	8.32	5.38	....	....	....	....	....	1.08	....	....	....
		22	0.44	0.26	0.95	9.46	5.92	....	....	....	....	....	1.18	....	....	....
		41	0.47	0.35	0.39	10.0	5.60	....	....	....	....	....	1.03	....	....	....
		42	0.49	0.35	0.38	11.7	4.92	....	....	....	....	....	0.98	....	....	....

ium, silicon and high carbon or nickel content, a high pouring temperature tends to produce a coarse grained dendritic pattern of ferrite and carbide material.

Either the crucible mixing or ferroaluminum method should prove very satisfactory for large or small scale production, provided a basic instead of acid electric furnace is used for melting. A thoroughly deoxidized bath should be maintained before making the aluminum addition. A low pouring temperature and rapid cooling after casting are desirable.

Several of the compositions were made by miscellaneous methods. Steel 1 was made by adding a rod of aluminum directly to the molten bath in the furnace. Steels 2 and 3 were made by pouring molten steel and molten aluminum simultaneously into a crucible and mixing. Steels 4, 58, 61, 62, 63, 65, 66 were made by introducing sheet iron boxes, containing cast aluminum into the molten bath in the furnace and holding the container under the slag until dissolved. This method worked very well in the small furnace. For large scale production however, the miscellaneous methods are not believed to be as applicable as the first two mentioned.

In general, the aluminum steels poured very "dead" and piped excessively. With the exception of some of the nickel-bearing steels, the majority of the compositions were quite soft as cast and Brinelled about 286. In this condition, they were machinable. Tests for chemical homogeneity were made on a number of ingots both in the cross sectional and longitudinal planes and it was found that none of the alloying elements varied unduly from one portion to another. The test ingots were annealed at 1650 degrees Fahr., hammer-cogged to $1\frac{3}{4}$ -inch square billets, annealed again, ground and rolled into $\frac{1}{4}$ -inch round bars. Sections of these bars were used for the tests described below.

In analyses Table I is found a complete list of all the compositions made and investigated. The determinations given are averages of several samples taken from the finished test bars. The method of determining the aluminum percentage is given in detail in the appendix. The steels are numbered and arranged in groups according to the alloys and amounts contained.

METHODS USED IN THE DETERMINATION OF PHYSICAL PROPERTIES

(1) *Effect of thermal treatment on hardness and micro-*

structure. Disks approximately $\frac{3}{8}$ inch thick were cut from the $\frac{1}{4}$ -inch round bars and hardened at intervals of 100 degrees Fahr. from about 1450 to 2350 degrees Fahr. in a semimuffle gas furnace. The specimens were preheated 5 minutes and held at the hardening heat for 5 minutes. The majority of the disks were water-quenched. Rockwell C, Brinell, longitudinal fracture and micro-examination tests were made on these samples. In order to obtain a more complete history of the structural changes occurring upon heating, 1-inch long samples were placed $\frac{1}{8}$ inch under water and heated on the opposite end to fusion by means of a blow torch. After heating for about $1\frac{1}{2}$ minutes, the piece was quickly quenched all over in water. A longitudinal section was then cut for micro-examination.

Depending on analysis, specimens for micro-examination were etched in either a 10 per cent solution of aqua regia in alcohol or a 5 per cent nital solution.

(2) *Resistance to oxidation at elevated temperatures.* Specimens of the various compositions in the annealed condition, were tested in the form of hollow cylinders, $\frac{1}{2}$ inch long by $\frac{5}{8}$ inch outside diameter, through which a $\frac{1}{4}$ -inch hole had been drilled. Ten or twelve of these cylinders of different composition were mounted on a $\frac{1}{4}$ -inch rod, separated from each other by thin mica sheets and bolted securely at the ends. The resultant "bar" was then subjected to the test, by suspending in a semimuffle gas furnace of considerable volume for a definite temperature and time. As "dry" a flame as possible was maintained throughout every test. At the end of the test, the gas and air were shut off and the specimens allowed to cool to room temperature in the furnace. In every group, was placed at least one sample of a standard chromium-silicon or chromium-aluminum steel for purposes of comparison. Temperatures of 1450, 1500, 1650 and 1850 degrees Fahr. were used. The time at heat consisted of 12 and 18-hour periods, exclusive of the heating or cooling time. This type of test, in which the specimens are exposed to the hot furnace gases, is quite severe and it is believed that the scaling values given under "results" may be considered a very safe minimum. After removal from the furnace, the amount and type of scale of each specimen were carefully noted by visual examination only, compared with the standard samples and given an oxidation rating.

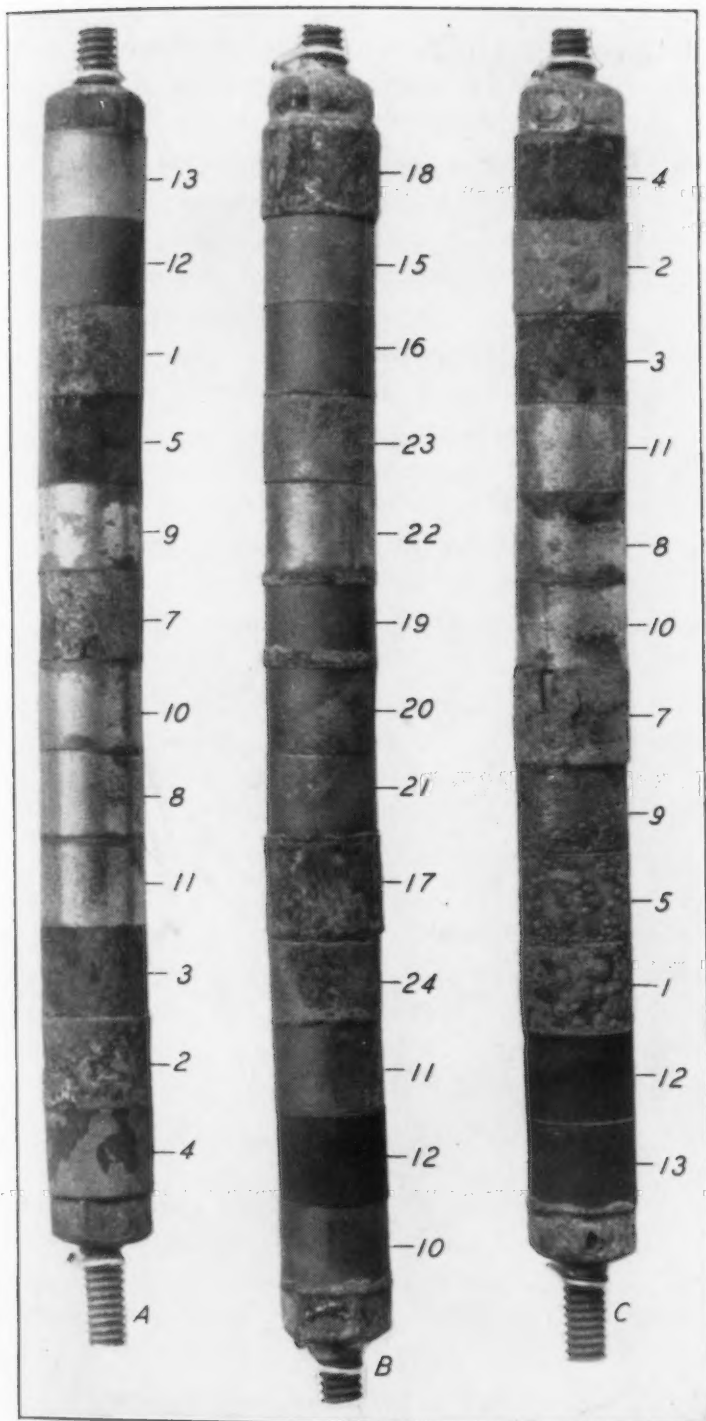


Fig. 1—Photographs Showing Method of Mounting and Appearance of Several Groups of Steels After Exposure to an Oxidation Test at Elevated Temperatures.

Fig. 1 shows the method of mounting and the appearance of several groups of steels after exposure to a hot oxidation test.

(3) *Resistance to atmospheric corrosion.* Since most of the steels could not be hardened to any appreciable extent, a comprehensive corrosion test was difficult to make with the high carbon percentages found in these particular steels. It was then decided to test the compositions in the annealed state. While this method of testing would not necessarily develop the maximum resistance to corrosion of many of the alloys, it did serve to classify the various compositions and indicate the general trend of characteristics. Polished cylinders, 1 inch long by $\frac{5}{8}$ inch diameter were placed on glass supports and exposed to winter weather for 107 days. This time limit was merely a matter of convenience. Examinations were made from time to time, as well as a final examination at the end of the test period and the type and amount of corrosion carefully noted by visual examination. Samples of stainless iron (12 per cent chromium and 0.09 per cent carbon) and hardened stainless steel (13 per cent chromium and 0.30 per cent carbon) were exposed at the same time for comparison purposes. The various alloys were given a rating and classified according to their surface condition. Although the test was only of a general nature, it served its purpose satisfactorily.

(4) *Forgeability.* Along with observations taken when the test ingots were hammer-cogged, it was decided to obtain more exact data on this property. Accordingly, specimens were prepared having a length twice the diameter (1 by $\frac{1}{2}$ inch) and were upset on end to a disk of thickness equal to $\frac{1}{3}$ the original diameter (approximately $\frac{5}{32}$ inch). The specimens were heated in a small oil-fired furnace and held at heat about 15 minutes. They were then removed and forged under a 500-pound hammer as quickly as possible to the correct sized disk.

(5) *Tensile strength at normal and elevated temperatures.* For room temperature tests, a specimen was used, having 4-inch long grips of $\frac{1}{4}$ inch diameter and a center reduced section of the standard 0.505 inch diameter and 2 inch length. A pulling speed of 0.05 inch per minute was maintained until fracture occurred. The testing machine was a 100,000-pound universal testing machine equipped with automatic recorder.

For high temperature tests, the same type specimen was used

1929

with longer grip lengths. A carbon combustion furnace about 12 inches in length was mounted vertically between the heads of the testing machine. The test piece was inserted so that the reduced section to which a thermocouple point had been attached, would occupy a central position. The ends of the furnace were then plugged with asbestos packing. Temperature was controlled by a rheostat and the samples held 30 minutes at heat before applying any tension. The speed of pulling was maintained at 0.05 inch per minute until fracture occurred. The elastic limit was not determined.

(6) *Impact Values.* An unnotched specimen 0.394 inch square by 2.94 inches long was used for the Izod impact tests. It was preferred to use the unnotched specimen as the values obtained on most of the steels were quite low. 120 foot-pound blow was applied.

RESULTS

Effect of Thermal Treatment on Hardness and Microstructure

Although a wide variety of compositions were investigated, those steels of basic composition fortunately adapted themselves to a systematic arrangement of characteristics, and it is believed that a sufficiently comprehensive conception of this data can be conveyed by merely emphasizing the trend of structural and physical changes and citing outstanding examples of the different types. It is not within the scope of this discussion to define exact limits of structural changes.

Group 4 of analysis Table I is comprised of alloys containing various percentages of carbon, chromium, aluminum and silicon, which elemental combinations constitute the nucleus of the investigation. The properties imparted to steel by carbon, chromium and silicon are of general knowledge and need not be emphasized again. The effect of aluminum, however, will be briefly discussed along with the general characteristics of the group. Steels 1 to 49 inclusive in group 4 represent the major portion of a series of alloys depicting the gradual elimination of the gamma phase. Steel 1, containing the least percentage of aluminum (2.47 per cent), upon heating, exhibits the normal alpha to gamma transformation with the latter phase predominating at high temperatures. Steel 49, containing as much as 5.38 per cent aluminum in

combination with a high chromium content, is dominantly ferritic at all temperatures. Steels of intermediate percentages of aluminum and chromium, upon heating, produced various amounts of alpha and gamma iron, which phases gradually approached a state of equilibrium. The above series of compositions was found to be quite analogous to certain high chromium-iron alloys.

Due to differences in casting conditions and analysis, two types of annealed microstructures resulted, differing in grain size and form and distribution of the carbide phase. The first type consisted of a banded structure of ferrite "stringers" in a matrix of finely spheroidized carbides as shown in Fig. 2, Steel 8. Fig. 3, Steel 10, exhibits the other type of annealed structure, consisting of fairly large spheroidized carbides in a ferrite matrix.

The air hardening properties of group 4 were practically nil. Steel 1, as rolled or air-cooled in thin section from about 2000 degrees Fahr. tested 24 Rockwell C, while in the fully annealed condition, it tested 15 C. As the aluminum content increased, smaller differences were noted between the "as rolled" and annealed conditions. Steel 11 tested 32 C in both rolled and annealed states.

The A_{c1} temperatures were very high. In determining the approximate position of this change point, microscopic examinations were made of a series of water-hardened samples and the temperature noted at which the first appearance of martensite or austenite was observed. The usual apparatus recording critical temperatures up to 1800 degrees Fahr. was useless, and even if suitable apparatus for recording temperatures over 1800 degrees Fahr. had been available, it is not believed that a definite critical point would be charted due to the sluggish transformations occurring in the compositions concerned. Accordingly, the A_{c1} temperature for Steel 1 was determined as approximately 1800 degrees Fahr. As the percentage of aluminum or chromium increased, other elements about the same, the A_{c1} temperature was elevated. Steel 11 indicated an A_{c1} point at approximately 2100 degrees Fahr. Steel 49, containing both high chromium and aluminum, remained completely ferritic at all temperatures up to fusion.

From an examination of aluminum steels of varying chromium content, it was observed that the number of degrees Fahr. increase in A_{c1} per one per cent of aluminum was dependent on

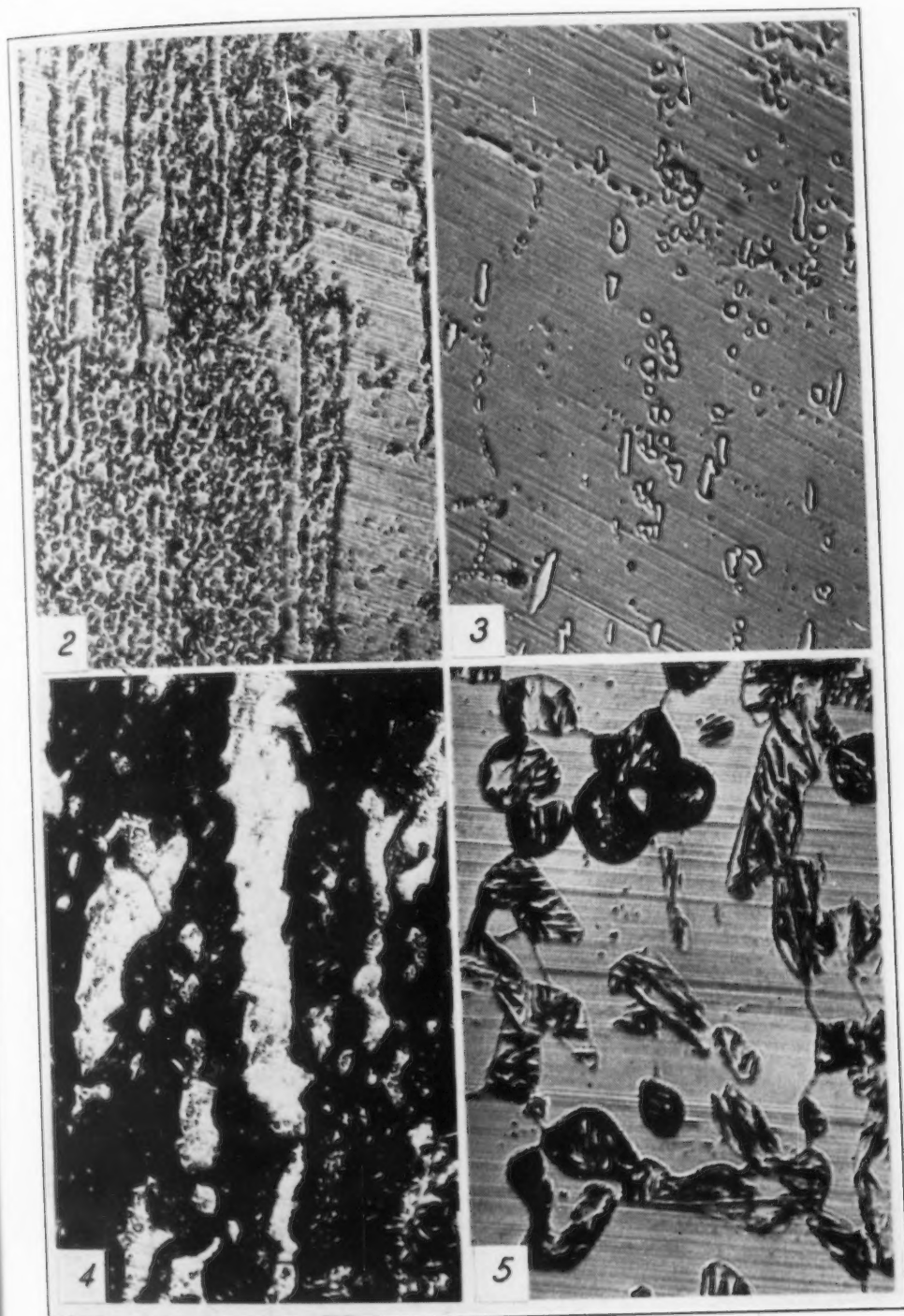


Fig. 2—Photomicrograph of Steel 8, Annealed. $\times 500$. Fig. 3—Photomicrograph of Steel 10, Annealed. $\times 500$. Fig. 4—Photomicrograph of Steel 8, Water-Quenched from 2250 Degrees Fahr. and Tempered at 1200 Degrees Fahr. $\times 500$. Fig. 5—Photomicrograph of Steel 10, Water-Quenched from 2250 Degrees Fahr., and Tempered at 1100 Degrees Fahr. $\times 500$.

Table II
Ac₁ Temperatures of Several Aluminum Steels of Different Chromium Content

Steel	Type	Analysis						Approx. Ac ₁ Temp.	Approx. Increase Degrees Fahr. per 1 Per Cent Aluminum
		C	Mn	Si	Cr	Al	Ni		
Carbon	Cr-free	0.30	0.26	0.20	0.09	....	....	1380° F.	...
68		0.32	0.33	0.24	0.17	2.44	....	1400° F.	8
14	8% Cr	0.51	0.30	0.80	7.41	....	....	1500° F.	...
1		0.39	0.40	0.95	7.9	2.47	....	1800° F.	120
11		0.67	0.41	1.10	8.59	5.3	....	2100° F.	113
Stainless	12% Cr	0.26	0.19	0.67	12.2	1.13	0.45	1760° F.	220*

*Taken from Monypenny's "Stainless Iron and Steel".

the chromium content of the alloy. Table II gives the Ac₁ temperatures of several compositions of different chromium content, as determined by the microscopic examination of water-quenched specimens. It will be noted that as the chromium content increased, the temperature increase in Ac₁ attributable to the presence of one per cent aluminum, is increased. This high critical range explains the absence of any possible lamellar pearlite in the annealed samples since the annealing temperatures were all below 1800 degrees Fahr. and simply produced a granulating or spheroidizing action on the existing sorbitic structure. In several instances, a lamellar structure was produced by a long high temperature anneal followed by suitable cooling. The pearlite formed, however, lacked the regularity of carbon steel pearlite and usually exhibited some incipient spheroidization.

In attempting to determine the Ac₃ temperatures in the same manner as the Ac₁, difficulty was encountered due to the extreme sluggishness and stability of the alpha phase. In a normal pearlitic steel such as 1, of group 4, holding at a hardening heat of 2250 degrees Fahr. for a normal time and quenching in water, resulted in a microstructure of approximately ten per cent undissolved ferrite "stringers" in a martensitic matrix, retaining a very small amount of austenite. The hardness developed was 54 Rockwell C. Heating up to the fusion temperature reduced the amount of undissolved ferrite to about four per cent. Also, holding the sample at 2250 degrees Fahr. for several hours and quenching in water, reduced the amount of undissolved ferrite to approximately two per cent, and resulted in a hardness of 60 C. Thus the Ac₃ temperature of Steel 1 may be considered as being

slightly over 2250 degrees Fahr.—presumably at about 2300 degrees Fahr. It is apparent even in this low aluminum content alloy, high temperatures and prolonged heating periods are necessary for the solution of the free ferrite into gamma iron. And a drastic quench is required to prevent the precipitation of any free ferrite from the gamma iron solid solution when cooled. Increasing the carbon content facilitated the solution of the alpha phase, thereby increasing the maximum hardness value, and produced a more stable gamma phase.

Steels of approximately the same carbon, chromium and silicon content as 1, but of increasing aluminum content, exhibited more undissolved ferrite at any given hardening temperature or time, and consequently required higher temperatures and longer heating periods to produce any appreciable solution. With a sufficiently high aluminum content, the ferrite remained stable at all temperatures and heating periods. Therefore, while it was possible to determine approximately the A_{c3} temperature, in the manner described above, for a steel of composition 1, it was impractical to attempt the necessary higher temperatures and longer soaking periods for steels of increasing aluminum content.

As the alpha phase increased in stability, it became more difficult to harden the steels. Thus for Steel 11, the maximum possible hardness was 37 Rockwell C. Depending on analysis, the compositions between Steels 1 and 11 of group 4 were capable of developing intermediate hardness values, that is between 60 and 37 C. Fig. 4, Steel 8, shows the microstructure of a typical "banded" pearlitic steel in the hardened and tempered condition. The fact that the hot working temperatures were at least several hundred degrees below the approximate A_{c3} temperatures, made a complete recrystallization and refinement of the cast structure impossible.

The other type of annealed microstructure, consisting of large carbide spheroids in a ferrite matrix, when quenched from high temperatures, exhibited a slightly different hardened structure. Thus, Steel 10, containing 4.6 per cent aluminum when heated permitted increasing amounts of gamma iron to form in those regions of greatest carbide concentration and after water quenching from 2250 degrees Fahr. and tempering at 1100 degrees Fahr., exhibited a structure of martensite and ferrite as shown in Fig.

5. Carbon played its usual important part in this type of structure since it materially facilitated the formation of large pools of austenite. The maximum hardness obtainable with Steel 10 was 40 C Rockwell. Steel 49, having a similar annealed structure, contained sufficient aluminum, chromium and silicon to entirely suppress the formation of any gamma iron at high temperatures. In compositions of this type, alpha iron is continuous and identical with delta iron. Heating to 2350 degrees Fahr., produced incipient fusion and developed a network of eutectic and carbide material around enlarged alpha grains, which latter, upon quenching, precipitated out numerous fine carbide particles formerly held in solution. The hardness developed was 37 Rockwell C, Fig. 6, shows the microstructure of Steel 49 after quenching in water from 2350 degrees Fahr.

Group 4 steels when reheated after quenching did not decrease appreciably in hardness until temperatures of over approximately 1100 degrees Fahr. had been reached. In several instances austenite was observed in samples reheated to 1200 degrees Fahr. The presence of aluminum retarded tempering and decidedly increased the tempering range. Throughout the entire series, the stability of the alpha phase is attributed principally to the aluminum content; chromium and silicon being of secondary importance. For example Steel 68, containing only a small amount of chromium and having an aluminum content equal to that of Steel 1, exhibited an alpha phase of approximately the same degree of stability as that found in Steel 1. Steel 14 containing no aluminum but having chromium and silicon in amounts approximately equal to Steel 1, showed a complete gamma iron solid solution at a temperature of 1850 degrees Fahr. Thus, aluminum can be considered a much more effective alpha phase stabilizer than either chromium or silicon in the amounts concerned.

Except for the lower silicon content, group 5 is similar in composition to group 4 steels. The only noticeable difference produced by this decreased silicon content, was the lowering by some 5 to 10 points Rockwell C of the air-cooled and annealed hardness values. This indicated quite definitely that silicon may be considered a ferrite "stiffener" in distinction to aluminum which does not possess this property.

EFFECT OF OTHER ALLOY ADDITIONS

In a steel of the following approximate analysis, carbon 0.40 to 0.60 per cent, chromium 8 to 10 per cent, aluminum 4 to 6 per cent, and silicon 1.0 per cent maximum, the effect on hardness and microstructure of the following single and combination alloy additions was found to be practically negligible:

Manganese	up to 2.54 per cent.....	Group 6
Tungsten	up to 3.0 per cent.....	Group 7
Molybdenum	up to 0.90 per cent.....	Group 8, 15
Cobalt	up to 2.93 per cent.....	Group 9
Copper	up to 1.26 per cent.....	Group 6, 7, 15

Vanadium at approximately one per cent (group 16) refined the grain of alloys containing as high as 5.92 per cent aluminum to a degree comparable to an annealed carbon tool steel.

Nickel produced a decided change in characteristics. A study of groups 10 to 14 inclusive indicated that in general, the effect of nickel was similar to that produced in any chromium or carbon steel. However, in the particular steels concerned this usual effect did not become evident until the ratio of the per cent nickel to the total percentages of chromium, aluminum and silicon exceeded a certain value. When this ratio value was approximately 0.20 or less, the effect of nickel was neutral or entirely masked by the predominating, counteracting influences of chromium, aluminum and silicon. When the ratio value was in excess of approximately 0.20, the effect of nickel was to produce a definite lowering of the critical range along with a widening and stabilizing of the gamma phase. The designation of a fixed value for this ratio can only be considered applicable to steels within the composition limits of groups 10 to 14 inclusive. At best, the value is only an approximation since a comparatively few steels were available for its determination.

Accordingly, in the nickel-bearing compositions, there was produced a series of steels analogous to the group 4 series first mentioned, depicting the gradual elimination of the gamma phase, but not to the same extent. The three distinct types of nickel alloys are best exemplified by the following study of Steels 3, 23 and 57. The ratio value of the first two steels is over 0.20, while that of Steel 57 is less than 0.20.

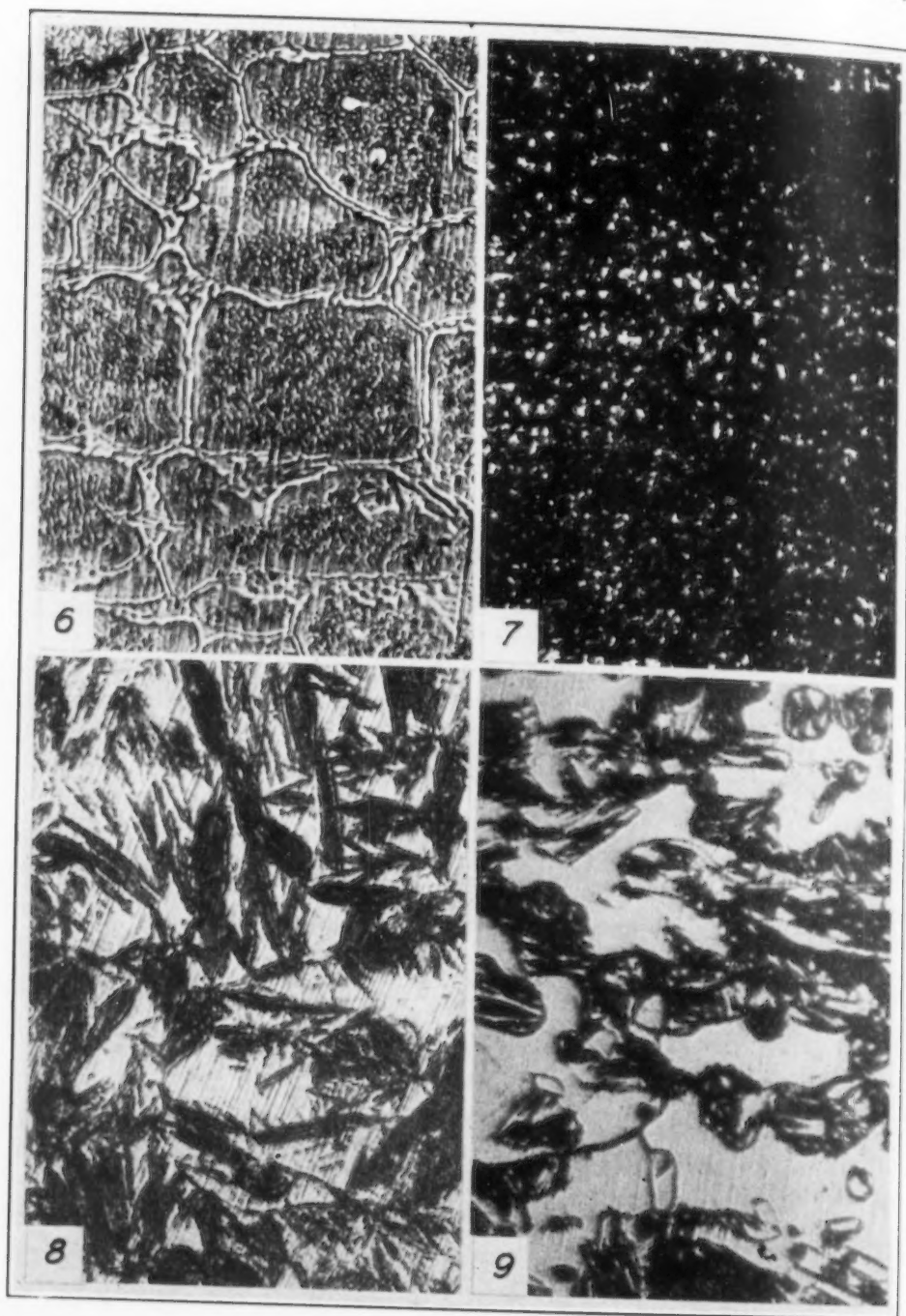


Fig. 6—Photomicrograph of Steel 49, Water-Quenched from 2350 Degrees Fahr. $\times 500$.
 Fig. 7—Photomicrograph of Steel 3, Annealed. $\times 500$. Fig. 8—Photomicrograph of Steel
 3, Oil-Quenched from 2250 Degrees Fahr. $\times 500$. Fig. 9—Photomicrograph of Steel 23,
 Water-Quenched from 2250 Degrees Fahr., and Tempered at 1100 Degrees Fahr. $\times 500$.

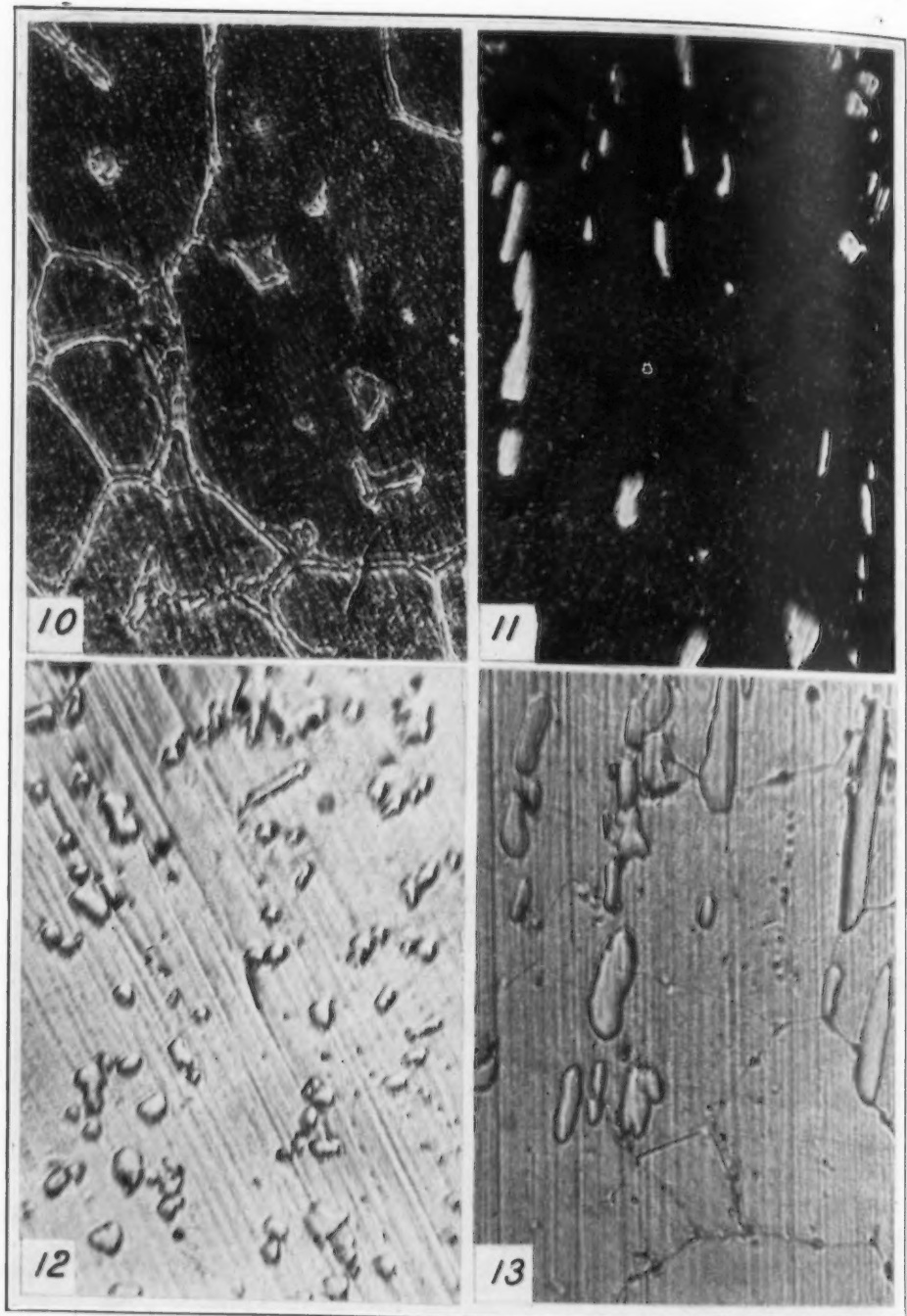
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Steel 3 of group 10, containing 6.62 per cent nickel and having a ratio value of 0.45, is an example of a composition capable of a complete alpha to gamma transformation, and is similar to any normal hardening steel. Fig. 7 shows the annealed, pearlitic structure. Fig. 8 exhibits the martensitic-austenitic structure produced by quenching in oil from 2250 degrees Fahr. Due to the austenite, the hardness as quenched was only 38 C Rockwell. The amount of nickel present reduced the A_{c1} temperature about 400 degrees Fahr. and the A_{c3} temperature from fusion down to a temperature of about 2200 degrees Fahr. The "as rolled" or air-cooled hardness was 40 to 43 Rockwell C and the annealed value was approximately 30 C. Nickel definitely increased the air hardening qualities and made soft annealing very difficult.

Steel 23 having a ratio value of 0.27 and containing about the same aluminum content as Steel 3, but with less nickel, exhibited a more stable alpha phase and at high temperatures consisted of alpha and gamma iron in equilibrium. Fig. 9 shows the microstructure of this steel in the hardened and tempered condition. The maximum hardness obtained was 50 Rockwell C. This value may be increased slightly by quenching from a temperature near fusion or holding several hours at 2350 degrees Fahr. However, with all the treatments tried, it was found impossible to produce a 100 per cent solution of the ferrite in the gamma iron. Steel 57 of group 11, containing 2.75 per cent nickel and having a ratio value of 0.17, is typical of those nickel compositions remaining ferritic at all temperatures up to fusion. Heating to 2350 degrees Fahr. produces incipient fusion in the carbide-rich areas and a network of eutectic and carbide material develops about the enlarged alpha grains. The latter, when quenched, precipitate out numerous fine carbide or austenite particles at the cleavage planes. At magnifications of about $\times 1000$, a fine Widmanstätten pattern is clearly discernible. Quenching in water from 2350 degrees Fahr., produced a hardness of 38 C and a microstructure as shown in Fig. 10.

In all the nickel steels of groups 10 to 14 inclusive, with the exception of 50 and 51 containing only very small amounts of nickel, an unusual low temperature alpha phase phenomenon, occurred. Regardless of the initial type of structure, heating in excess of about 1250 degrees Fahr. (preferably 1300 degrees Fahr.)



Figs. 10 to 13, Inclusive. Photomicrographs of Steel 57. Fig. 10—Water-Quenched from 2350 Degrees Fahr. $\times 500$. Fig. 11—Annealed, Rockwell C 31-33. $\times 1000$. Fig. 12—Water-Quenched from 1350 Degrees Fahr., Rockwell C 31-33. $\times 1000$. Fig. 13—Water-Quenched from 1350 Degrees Fahr., and Tempered at 1100 Degrees Fahr., Rockwell C 45. $\times 1000$.

and quenching in oil or water, followed by reheating to 950 to 1150 degrees Fahr. and cooled in any manner produced a decided increase in hardness over that of the quenched condition. For example Steel 57, after a long thorough anneal, tested 31 to 33 C Rockwell and exhibited a structure as shown in Fig. 11. Heating to 1350 degrees Fahr. for 30 minutes and quenching in water changed the structure to that shown in Fig. 12 but did not alter the hardness value. Reheating the quenched sample to 1100 degrees Fahr. for one hour, followed by air cooling, increased the hardness to 45 C Rockwell and produced a structure as shown in Fig. 13. This same 10 to 15 point increase in hardness was obtained with all the nickel steels given this treatment, regardless of composition. Maximum softness was produced by either quenching from about 1300 degrees Fahr. or annealing for a long time. Although these two methods produced the same hardness, the microstructure was entirely different and only the quenched sample would increase in hardness after reheating to about 1100 degrees Fahr. Holding the quenched sample at this reheating temperature of 1100 degrees Fahr. for about 400 to 500 hours, changed both structure and hardness back to that of the annealed state.

Experiments thus far indicate that the sorbitic appearance of the annealed sample is due to the precipitation of minute carbide particles formerly in solution in the alpha phase. Heating the annealed sample to 1300 degrees Fahr. appeared sufficient to dissolve these particles in the alpha iron and quenching retained them in this condition. The increase in hardness after reheating to 1100 degrees Fahr. is believed due to the precipitation of sub-microscopic carbides in a state of critical dispersion.

There were slight evidences of a similar phenomenon in several of the high aluminum nickel-free steels, occurring only at higher quenching temperatures. The change, however, was of insufficient intensity to reveal any differences in microstructure and consequently its nature could not be ascertained.

RESISTANCE TO OXIDATION AT ELEVATED TEMPERATURES

Steels of group 3, containing only aluminum as the main alloying addition, sealed appreciably at 1450 degrees Fahr. to about the same extent as any plain carbon steel. The thickness of the

loose black gray scale, increased rapidly with rise of temperature. These observations indicated that as much as 4.2 per cent aluminum in combination with 0.80 per cent silicon does not aid resistance to oxidation of a plain carbon steel.

Group 4, containing chromium as well as aluminum and silicon, exhibited a marked increase in heat resisting properties. At 1450 degrees Fahr. only a red shiny discoloration or scale of imperceptible thickness was formed on Steels 1 to 8, group 4. The amount of this discoloration decreased as the chromium, aluminum and silicon contents increased up to that composition of Steel 49. At 1550 degrees Fahr. a slight black scale was formed on Steel 1 containing 2.47 per cent aluminum, 7.9 per cent chromium, and 0.95 per cent silicon, and this temperature was considered the scaling point. In the same manner, 1850 degrees Fahr. was found to be the approximate scaling point of Steel 49 containing 5.38 per cent aluminum, 12.76 per cent chromium, and 0.83 per cent silicon. With the intermediate steels of this group, the scaling points occurred between the temperatures of 1550 and 1850 degrees Fahr., the exact temperature depending on the relation of their particular total percentages of chromium, aluminum and silicon to those of Steels 1 and 49. In other words, the degrees of scaling and the temperature at which scaling started, were found to be dependent primarily on the total percentage of chromium, aluminum and silicon, with the aluminum and silicon exerting the predominating influence in the particular chromium ranges concerned. The effect of variations in carbon from 0.37 to 1.08 per cent or manganese from 0.28 to 0.45 per cent were negligible.

A representative analysis capable of withstanding any appreciable degree of surface oxidation at 1650 degrees Fahr. is that of Steel 8, containing 3.9 per cent aluminum, 8.6 per cent chromium, 1.1 per cent silicon, 0.34 per cent manganese and 0.62 per cent carbon. There was no composition in group 4 of sufficiently high total percentage of chromium, aluminum and silicon to be totally immune to oxidation at a temperature as high as 1850 degrees Fahr.

The development of scale on group 4 steels usually proceeded from a red discoloration to a loose mottled gray-black scale, which started at isolated points and grew to form a continuous enveloping coating. As the type of scale would suggest, once the adherent smooth red thin scale or discoloration was penetrated, the loose

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Table III

Effect of Various Alloys on the Heat Resisting Properties of
Chromium-Aluminum Steels

Alloy	Per Cent Used	Effect	Characteristic type of scale
Manganese	0.90 to 2.54	detrimental	gunmetal color—raised oxide particles
Vanadium	up to 2.13	neutral	regular for Group 4
Tungsten	up to 4.91	desirable	close smooth red-brown scale
Molybdenum	up to 1.00	desirable	close smooth black-brown scale
Cobalt	up to 2.93	neutral	gunmetal color—raised oxide particles
Copper	up to 1.26	neutral	regular for Group 4
Nickel	up to 6.62	variable	variable

APPROXIMATE COMPOSITION

C 0.40-0.70 per cent, Cr 7.5-12 per cent, Al 3.5-6.0 per cent, Si 1.0 per cent max.

oxide subsequently formed, permitted a progressively increasing degree of scaling as time or temperature increased.

The temperature at which scaling started occurred 200 to 300 degrees Fahr. below the approximate A_{c1} temperatures and increased with A_{c1} as the percentage of chromium, aluminum and silicon increased. Accordingly, with compositions of this type, the A_{c1} temperature served as a fairly accurate indication of the scaling temperature or vice versa and suggested the possibility of a relationship between the two.

The 0.50 to 0.75 per cent lower silicon content as found in steels of group 5, reduced the resistance to oxidation and definitely indicated the importance of maintaining silicon at approximately 1 per cent which was chosen as the maximum amount for steels of this investigation.

The effect of other alloy additions is given in condensed form in Table III. The effect of tungsten and molybdenum in Table III were classed as desirable not so much for reducing the amount of scale, but for developing a particularly desirable type of scaled surface.

The variable effect of nickel depended on the value of the same ratio mentioned under metallographic data and should be considered with the same reservations as mentioned before. Thus, when the value of the ratio of the percentage of nickel to the percentage of chromium + aluminum + silicon exceeded approximately 0.20, the effect of nickel was detrimental, increasing the amount of scale and lowering the temperature at which scaling started. When the value was approximately 0.20 or under, the effect of nickel was neutral.

Table IV
Examples of Variation in Heat Resisting Properties of Nickel-Chromium-Aluminum Steels Due to Variations in Ratio Value

Steel No.	C	Mn	Si	Per Cent		Ni	Cu	V	Ratio Value	Amount of Scale at 1850° F.	Approx. temp. ° F. at which scaling starts
3	0.53	0.40	0.73	8.59	5.14	6.62	....	....	0.45	very heavy	1600
34	0.48	0.55	0.87	8.62	5.19	1.11	1.15	....	0.08	slight scale	1750
4	0.46	0.45	0.86	8.79	3.97	3.32	1.10	....	0.24	very heavy	1600
66	0.60	0.34	1.03	10.0	4.91	3.35	....	2.13	0.20	slight scale	1750

As an example of the influence of the ratio value, Table IV contains the analysis, ratio value and scaling properties of four typical steels. Steels 3 and 34 are examples of a variation in the ratio numerator with constant denominator while Steels 4 and 66 exhibit a variation in denominator with constant numerator. The copper and vanadium content of two of the steels need not be compensated for as these elements have previously been determined as neutral.

Steels 57, 60 and 22, found in groups 11, 12 and 16, are representative compositions containing sufficient chromium, aluminum and silicon with other elements in neutral amounts, to remain practically scale-free after exposure to a temperature of 1850 degrees Fahr. for 12 hours. After the removal of a slight fuzz, the original bright polished surfaces were revealed. It will be noted that the aluminum, chromium and silicon contents are approximately 5.5, 9.5 and 0.90 per cent respectively.

In the nickel steels there was additional evidence of a relationship between the heat resisting properties and A_{c1} temperatures. When nickel was of insufficient quantity to lower the A_{c1} temperature, no change occurred in the heat resisting properties. Sufficient nickel to lower the A_{c1} range, lowered the scaling temperature also. Although the exact nature of this relationship is not fully understood, the possibility of its existence appears quite probable.

RESISTANCE TO ATMOSPHERIC CORROSION

Referring to groups 1 and 3, it was found that a steel containing either 7.41 per cent chromium (14) or 4.2 per cent aluminum (18) possessed only ordinary resistance to atmospheric corrosion in the annealed state. The combination of chromium and alu-

1929

minum in approximately these same percentages, as found in various steels of group 4, produced an alloy having resistance superior to either of the first two steels mentioned. It may be assumed then that chromium and aluminum are of mutual benefit to each other. As the percentage of chromium and aluminum increased, other elements remaining the same, the corrosion resistance increased, but with exception of the nickel and copper-bearing steels, no alloy in the entire series possessed resistance to a degree approaching that of stainless iron containing 12.5 per cent chromium and 0.10 per cent carbon, maximum. This is due to the fact that in those annealed aluminum steels containing about 12 per cent chromium, which would ordinarily produce immunity to atmospheric corrosion, the high carbon present, detracted to a greater degree than the aluminum aided. Although the steels were tested in the annealed condition, the majority of the alloys would not show any appreciable difference in the heat treated condition due to the fact that they were practically nonhardenable and only slight carbide solution was possible. However, those alloys, capable of carbide solution at elevated temperatures, would be expected to show improved resistance in the heat treated condition.

Steels containing small percentages of nickel showed a little improvement over the same steel nickel-free.

Copper at approximately 1 per cent produced a very marked increase in corrosion resistance. In every case, the copper-bearing steels, regardless of other alloys present, showed exceptional resistance. Steel 37, group 7, analyzing carbon 0.48 per cent, manganese 0.61 per cent, silicon 0.89 per cent, chromium 9.37 per cent, aluminum 5.05 per cent, copper 1.26 per cent, tungsten 1.55 per cent, in the annealed condition (Rockwell 27 C), exhibited a better surface than stainless iron and nearly equal in quality to the surface of hardened stainless steel after 6 months exposure to winter weather. This same aluminum steel with carbon under 0.10 per cent would no doubt be as resistant to atmospheric corrosion as hardened stainless steel.

Small amounts of vanadium, molybdenum, cobalt, tungsten, and manganese, had a neutral effect while increased carbon decreased resistance but not to the extent produced in a straight chromium steel.

No extensive tests were made to determine the resistance to

acids, but it was observed that the entire series was readily attacked by dilute H_2SO_4 and HCl . Like other high chromium steels, nitric acid attacked the samples only slightly.

FORGEABILITY

Perfect forgeability, as considered from the standpoint of the standard upsetting test mentioned under description of tests was exhibited by the following typical steels; groups 3 and 5, Steels 1 to 8 inclusive in group 4, and Steels 31 and 35 in group 15. In the carbon-aluminum steels of group 3, up to 4.2 per cent aluminum with 0.80 per cent silicon did not interfere with the normal perfect hot working qualities of a carbon steel. In the chromium-aluminum steels, however, with the carbon, chromium and manganese within the composition limits of groups 4 and 5, the forging qualities depended on the total aluminum and silicon content. At this time, a conservative estimate of the analysis limit of perfect forgeability would be at a maximum total content of aluminum and silicon of approximately 5.5 per cent with silicon not exceeding about 1 per cent. No doubt, more careful manufacturing and forging practice would increase this maximum value.

Group 3 steels and steels 1 to 8 in group 4, forged well, from 2100 to 1400 degrees Fahr. with equally good forging results. However, from the standpoint of the structural and physical properties induced, a high range of 2100 to 1900 degrees Fahr. is preferred. Those steels of groups 5 and 15 forged best at 1700 to 1400 degrees Fahr.

In general, steels containing a total aluminum and silicon content of over 5.5 per cent did not possess consistently perfect hot working qualities. Forging to a thin disk as described, usually resulted in the formation of one or more cracks at the edges. The forging test in question is quite severe, and it is not desired to infer that the higher aluminum and silicon steels exhibited poor forgeability as ordinarily considered. Certainly in the hammer cogging and rolling operations, no serious difficulty was encountered with any of the compositions investigated. 1700 to 1400 degrees Fahr. was found to be the best forging range for steels of over 5.5 per cent total aluminum and silicon content, and containing other elements within the analysis limits of the investigation.

Table V

Tensile and Impact Values of Typical Chromium-Aluminum Steels
at Normal Temperatures

Steel No.	Analysis, Per Cent								C, Rockwell	1000 lb. Sq. In. Ultimate		1000 lb. Sq. In. Elong. in 2 in.	Per Cent Elong. in 2 in.	Per Cent R. A.	Izod Impact, ft. lbs.	
	C	Mn	Si	Cr	Al	Cu	Mo	1000 lb. Sq. In. Ultimate		1000 lb. Sq. In. Elong. in 2 in.						
8	0.62	0.34	1.1	8.6	3.9	....	....	23	112	87	22.6	45.5	118	no	break
								41*	173	160	13.3	32.9	117	no	break	
39	0.42	0.29	0.22	8.83	5.14	....	....	13	90	60	29.6	57.6	116	no	break
10	0.37	0.33	1.08	4.29	4.60	....	....	15	90	70	5.5	5.1	40		
11	0.67	0.41	1.10	8.59	5.30	....	....	31	125	105	3.1	3.5	23		
35	0.43	0.47	0.87	8.47	4.45	1.04	0.90	24	108	82	22.6	48.4	116	no	break	

*Heat treated 2250 degrees Fahr., quenched in water, tempered at 1200 degrees Fahr.

With the exception of nickel, the addition of other alloys in the small amounts concerned, did not affect forgeability. The nickel-bearing compositions required more care, but under proper conditions, forged satisfactorily. When the nickel content was sufficient to produce a marked alpha to gamma transformation, the most desirable physical properties resulted after a high forging range of approximately 2000 to 2200 degrees Fahr. When the steel was dominantly ferritic, the most desirable forging range was at 1800 to 1500 degrees Fahr.

TENSILE STRENGTH AT NORMAL AND ELEVATED TEMPERATURES

Assuming an approximate average composition of carbon from 0.35 to 0.70 per cent, manganese 0.50 per cent maximum, and chromium from 8 to 10 per cent, tensile values depended primarily on the total percentage of aluminum and silicon. With silicon at approximately one per cent and aluminum below about 4 per cent, or silicon decreasing to approximately 0.25 per cent or less with aluminum increasing up to about 5.2 per cent, normal values of good strength and ductility were obtained. Either aluminum or silicon in excess of the above limiting ranges, decreased the ductility without materially affecting the ultimate strength. Table V gives the tensile and impact values of several typical steels.

Table VI
High Temperature Tensile Values of Typical Chromium-Aluminum Steels

Steel No.	Analysis, Per Cent								Temp. of Test, Degrees Fahr.	Lb. Per Sq. In., Ult.	Per Cent Elongation in 2 in.	Per Cent Reduction of Area
	C	Mn	Si	Cr	Al	Cu	Mo	Ni				
8	0.62	0.34	1.1	8.6	3.9	....	....	....	1500	9500	67.9	95.9
59	0.47	0.40	3.15	8.37	....	....	....	....	1650	5450	85.9	98.1
35	0.43	0.47	0.87	8.47	4.45	1.04	0.90	....	1500	7600	62.5	97.6
63	0.50	0.29	0.89	8.93	4.62	1.07	....	3.13	1500	5075	47.4	97.3
									1500	7350	78.1	91.3
									1500	9050	46.8	91.9

With the one exception noted, all values were taken from annealed samples.

With the exception of vanadium, small amounts of other alloys added, did not produce any noticeable change in the tensile properties. About 1 per cent vanadium added to a steel of general analysis, carbon 0.40 to 0.50 per cent, silicon 0.40 maximum per cent, and chromium 8 to 12 per cent, permitted the aluminum content to increase to 5.6 per cent without decreasing the ductility or impact values. Any effect which the other alloys might ordinarily exert was no doubt completely masked by the predominating influences of the basic elements, carbon, chromium, aluminum, and silicon. For example, in the nickel steels, there was no indication of any additional toughness. In fact in the higher aluminum steels, 2 to 3 per cent of nickel appeared to further decrease the low ductility values.

Table VI gives typical results of tensile values at high temperatures. Values of a chromium-silicon steel are included for comparison. It will be noted that the strength at 1500 and 1650 degrees Fahr. of the aluminum steels compares favorably with that of chromium-silicon steel.

IMPACT VALUES

The impact values were found to vary directly with the ductility values in the tensile determinations and the same com-

position limits apply to both properties. Typical values are included in Table V.

SUMMARY AND CONCLUSIONS

The particular chromium-aluminum steels investigated are characterized briefly as follows. Alloys containing about 2 to 6 per cent aluminum, 7 to 13 per cent chromium and 1 per cent maximum of silicon and carbon, possessed high critical ranges and a very stable alpha phase, the stability of which increased with increase in the aluminum, chromium, and silicon contents. Hardenability varied inversely with the stability of the alpha phase and directly with the carbon content. Steels containing about 5.5 per cent aluminum, 9.5 per cent chromium, 1 per cent silicon and 0.50 per cent carbon were dominantly ferritic at all temperatures. Depending on the total aluminum, chromium and silicon content, the alloys exhibited complete resistance to oxidation at temperatures from 1550 to 1850 degrees Fahr. The particular compositions investigated in the annealed condition were of no importance from the standpoint of resistance to atmospheric corrosion. Perfect forgeability characterized those steels containing a total aluminum and silicon content of not more than 5.5 per cent with silicon at a maximum of 1 per cent. Tensile and impact values depended primarily on the aluminum and silicon contents. With silicon at approximately 1 per cent and aluminum at about 4 per cent or less, or with silicon decreasing to about 0.25 per cent and aluminum increasing up to a maximum of about 5.2 per cent, normal values of good strength, ductility, and impacts, were obtained. Either aluminum or silicon in excess of the above limiting ranges, decreased the ductility and impact values without materially affecting the ultimate strength. Tensile values at high temperatures were exceptionally good.

The addition to the above basic composition range of any one of the alloying elements, nickel, tungsten, molybdenum, copper, vanadium, manganese or cobalt in the amounts covered by this investigation, affected the physical properties as follows:

The effect of nickel depended on the value of the ratio

$$\frac{\text{per cent nickel}}{\text{Total per cent aluminum} + \text{chromium} + \text{silicon}}$$

When this ratio value was approximately 0.20 or less, the effect of nickel on hardness, microstructure and heat resisting properties, was nil. When the ratio value exceeded 0.20, nickel lowered the critical range, produced a more stable gamma phase, a less stable alpha phase and lowered the scaling temperature. An unusual increase in hardness occurred in the nickel steels, by reheating to approximately 1100 degrees Fahr., following an oil or water quench from about 1300 degrees Fahr. Nickel slightly aided resistance to atmospheric corrosion and made the steels more sensitive to hot working.

Tungsten and molybdenum produced a desirable type of scaled surface in the oxidation tests at elevated temperatures and are considered suitable additions where this property is concerned.

Copper at 1 per cent produced a decided increase in resistance to atmospheric corrosion.

Vanadium at 1 per cent, extended the aluminum and silicon content limits for ductility and impact values to about 5.6 per cent aluminum with silicon under 0.40 per cent. Vanadium also aided grain refinement.

Manganese decreased resistance to oxidation at elevated temperatures.

The effect of cobalt was neutral to all the physical properties investigated.

APPENDIX

Some of the observations of other investigators, as they concerned this present research are briefly as follows:

Hadfield¹ found that aluminum did not affect the hardness of iron and its action in this respect was similar to that of silicon, sulphur, phosphorus, arsenic, and copper in contradistinction to carbon, manganese, chromium, tungsten, and nickel. About 5.6 per cent aluminum in a 0.20 per cent carbon steel was considered the limit for good malleability. Up to 5 per cent, aluminum had little influence on the mechanical properties of iron; over this percentage, the iron was stronger in tension but became brittle.

Gwyer's² equilibrium diagram shows that under approximately 34 per cent, aluminum remains in solid solution with iron at ordinary temperatures.

¹*Journal, Iron and Steel Institute.* Vol. 38, II 1890, pp. 161 to 230.

²*Zeitschrift für Anorganische und Allgemeine Chemie,* Vol. 57, 1908, pp. 113-153.

1929

Guillet³ found that the presence of aluminum prevented pearlite from assuming its ordinary form; the tendency being to form "little nodules". With an 0.80 per cent carbon steel, the limit of forgeability was found to be at an aluminum content of 7.18 to 9.25 per cent.

Monypenny⁴ found that the action of aluminum on stainless steels was similar to that of silicon, only much more pronounced. One per cent of aluminum raised the A_{c1} temperature 120 degrees Cent. and made the thermal curves indistinct. This same percentage prevented low carbon stainless steel from hardening to any extent, produced low impact values and coarsened the fracture. Aluminum at 1.5 per cent raised the scaling temperature from 825 degrees to 950 degrees Cent. Very high hardening temperatures were required to produce any carbide diffusion and hardening effect. Aluminum retarded tempering as well as the solution of free ferrite and even when in solution, promoted the instantaneous precipitation of ferrite when quenched from high temperatures.

Gatward and Yansen⁵ reported that aluminum up to 6 per cent increased the strength of carbonless iron in direct proportion to the amount added and affected toughness slightly. With alloys containing 0.10 per cent carbon, up to at least 8 per cent of aluminum had no marked effect upon either the strength or toughness of the alloy. It appeared that 0.10 per cent carbon was sufficient to completely mask the effect of aluminum. Alloys containing 0.40 to 0.60 per cent carbon were forgeable with an aluminum content up to 13 per cent. Such high aluminum compositions, however, were brittle.

The following method was used by our laboratory in determining aluminum in a steel containing chromium and aluminum.

One gram sample is dissolved in 60 cubic centimeters of HCl 1 to 1 solution. After solution is about complete oxidize with a few drops of HNO_3 . Evaporate solution to 10 to 15 cubic centimeters.

Transfer solution to a separatory funnel, using HCl 1 to 1 wash. Add 50 cubic centimeters of ether. Keep solution cold.

³Journal, Iron and Steel Institute, Vol. 70, II 1906, p. 16.

⁴Monypenny's "Stainless Iron and Steel."

⁵University of Illinois Engineering Experiment Station Bulletin 95, January, 1917.

Mix. Let settle. Draw off the bottom layer into another separatory funnel, and make another ether separation as before. Draw off the bottom layer into a 400-cubic centimeter beaker.

Evaporate off excess ether on a warm plate, and then evaporate to 15 cubic centimeters. Add 100 cubic centimeters of water. Oxidize the chromium with sodium peroxide, using an excess. Boil 5 minutes. Make up to a 250-cubic centimeter volume. Mix. Filter off 125 cubic centimeters, equivalent to one-half gram sample.

Add HCl in excess and boil. Add NH_4OH until there are 2 drops in excess, using methyl red indicator. Add paper pulp. Stir. Let the aluminum hydroxide precipitate settle.

Filter and wash with hot 2 per cent ammonium nitrate wash. Dissolve precipitate with 30 cubic centimeters of hot HCl 1 to 1. Reprecipitate the aluminum hydroxide with NH_4OH as before. Filter and wash well with 2 per cent ammonium nitrate wash.

Burn off in a weighed platinum crucible. Moisten with water. Add 1 drop H_2SO_4 1 to 1, and about 2 cubic centimeters of HF. Evaporate to fumes. Again ignite. Cool. Weigh. The difference in weight multiplied by 106.06 equals the per cent of aluminum.

DISCUSSION

Written Discussion: By V. O. Homerberg, Massachusetts Institute of Technology, Cambridge, Mass.

The authors are to be congratulated on the completion of such an exhaustive study of the effects of aluminum in steels containing combinations of various other alloying elements.

My remarks are entirely of a confirmatory nature. Although most of my study has been related mainly to nitriding steels containing not over 2 per cent of aluminum, some work has been done on steels containing higher amounts. The remarks made by the authors, especially the statement that the presence of aluminum in certain steels tends to enhance their resistance to scaling as well as to increase their tensile strength at elevated temperatures, are in agreement with my observations.

The results of a study of nitriding steels together with the results of the present investigation indicate clearly that aluminum is a valuable alloying element as well as an active deoxidizer.

Written Discussion: By George Charlton, Rich Tool Co., Detroit.

I wish to thank the Society for sending me a copy of the paper which has just been presented, thereby giving me an opportunity to study the work at leisure, and I wish to congratulate the authors on the painstaking and complete manner in which they conducted the investigation.

Having been a user of these types of steels for several years, I find myself agreeing with the authors' findings.

Regarding Forgeability. The test which is described on page 740, under forgeability, is a standard upsetting test with us; and, as an instance, steels containing carbon 0.50 per cent, 9.0 per cent chromium and 4.50 per cent aluminum will submit to the test and be readily forgeable.

Regarding Hardenability. Steels having approximately 8 per cent of chromium and 4 per cent aluminum can be hardened to 50 to 55 scleroscope, but as described under the thermal treatment, page 741, a high heat is required. The addition of nickel modifies this somewhat. The addition of nickel also has a marked refining influence on the fractures of those steels, and I wish that the authors had given us their observations on fractures.

Some of the heats produced without a nickel content show large crystal formations which are not easily broken up. The addition of one-half of one per cent or more nickel always produces greater refinement. Tungsten also has a refining influence, but not to the same extent as nickel and does not have the same influence on the critical points.

The effect of resistance to oxidation of these types of steel is well illustrated on page 739. It is a method which we have always used to demonstrate comparative resistance to oxidation. All of the disks of different steels on any one arbor must necessarily be subjected to the same conditions. In testing the comparative scale resistance of different materials, using an oxidizing atmosphere in the furnace for scaling, proper comparison can only be made when the pieces are run at the same time. That is, a sample of a steel scaled at a certain temperature cannot be compared accurately with a sample of another steel scaled at the same temperature several days later.

Aluminum, in combination with up to 10 per cent chromium, is not as effective as silicon in producing scale resistance at high temperatures. That is, taking steel No. 59, page 758, which has 3.15 silicon, 8.37 chromium and substituting 3.15 per cent aluminum for the silicon would make it inferior as a scale resistor at high temperatures, but raising the aluminum content to 4.50 per cent would make it better.

By using analysis No. 16, page 736, and raising the silicon content to 4 per cent a remarkable heat resisting material is produced which will not even lose its ground polish at 1800 degrees Fahr.

A very interesting part of the paper is the tensile strength at high temperatures, page 758, Table VI. In studying the figures given for steel No. 59, I note at 1650 degrees Fahr. a strength of 5075 pounds per square inch. This figure suggests that the tensile test pieces were tested in the annealed state. By taking steel of this analysis and heat treating it to obtain maximum hardness, and tempering at 1000 degrees Fahr., a tensile strength at 1650 degrees Fahr. of 8950 pounds per square inch has been obtained. It has been my experience on hot pulling tests that the strength at high temperature varies with the heat treatment, i. e., the greater the hardness obtained at the hardening operation the higher will be the value obtained in pounds per square inch. I mention this to suggest that all the

pounds per square inch figures given in Table VI may be raised by heat treatment.

Comparing the strength of steel No. 59 with the aluminum steel No. 8, we have also found the aluminum steel to have greater strength at 1650 degrees Fahr.

The paper clearly shows that in the range of chromium-aluminum steels with chromium 8 to 10 per cent, as the aluminum content increases scale resistance at high temperatures increases but the ability to obtain high hardness values decreases. When it is desirable to produce a high degree of resistance to oxidation and high hardness values for wearing qualities, then it is necessary to go to another series of chromium-aluminum combinations. A typical analysis of this series is 1.00 per cent carbon, 18.00 per cent chromium and 2 per cent aluminum, and this will give all around greater physical values than the series under consideration. This, however, is outside the scope of the present paper.

I hope that the authors of the paper will continue their investigation of these types, and I am sure that members present all thank them for generously giving us the result of their labors.

Written Discussion: By W. E. Giffiths, Duraloy Co., Pittsburgh.

The affinity of chromium for carbon in high chromium alloys is a well established fact. In all ranges of analyses, the alloys can dissolve in solid solution in the gamma phase an appreciable amount of carbon. However, the ferrite or alpha iron solid solution is not considered capable of dissolving the amount of carbon present in alloy 57 under discussion.

M. A. Grossmann, in a paper presented to the A. I. M. E. on "The Nature of the Chromium-Iron-Carbon Diagram", considers the solubility of carbon in an 18 per cent chromium-iron alloy as probably negligible. E. C. Bain, in a paper presented to the A. S. S. T. on "The Nature of the Alloys of Iron and Chromium", January, 1926, states that an amount as great as 0.20 per cent carbon may be soluble in ferrite after annealing. It is also stated in the same article that delta iron or the high temperature ferrite phase is capable of absorbing an even greater amount of carbon in solid solution. The temperature, 1350 degrees Fahr., is too low for the formation of delta iron and the one hour treating period used is very short to produce a carbide solution inasmuch as chromium irons are sluggish in their transformations.

There are two other possible explanations which should be considered in interpreting the observed facts. The first and more probable one is that the particles observed are nitrides. The appearance of carbides and nitrides, under the microscope, in these alloys is at present regarded as essentially identical. The temperatures of transformation in the case of alloy 57 are those which are favorable to the solution and precipitation of nitrides.

The second is that of the formation of a new phase or constituent such as was described by Bain and Griffiths in a paper, "An Introduction to the Chrome-Iron-Nickel Series" as presented to the A. I. M. E. in February, 1926. This constituent forms from the ferrite phase in certain ranges of

1929

chromium and nickel. The chromium and nickel present in alloy 57 are not sufficient to produce the new constituent, but the fact that both aluminum and vanadium are similar to chromium in their effect in stabilizing the ferrite condition, makes this phenomenon worthy of consideration.

Written Discussion: By P. A. E. Armstrong, consulting engineer, New York City.

I want to congratulate the authors on their painstaking investigation of a portion of the chromium-aluminum-iron and steel, alloy series. For many years I have conducted a very thorough research in this particular series and I find the authors' investigation and conclusion are similar to my own conclusions. Mr. Charlton's remarks are a very valuable addition to the paper.

Nickel as an addition to the chromium-aluminum steels adds to their atmospheric corrosion resisting properties but does not add to their heat or scale resisting properties, unless the nickel is high, that is more than a few per cent. With high nickel content, the nickel-chromium-aluminum series becomes distinctly different from the chromium-aluminum series, and incidentally different from the chromium-nickel-iron series. I consider, and my many years of research have proved, that the nickel-chromium-aluminum series is very markedly superior to the nickel-chromium-iron series, having some characteristics similar to nickel and chromium and other properties which make it a different alloy.

Authors' Reply to Discussion

In the first paragraph of W. E. Griffiths' discussion it is stated that "alpha iron solid solution is not considered capable of dissolving the amount of carbon present in alloy 57 under discussion". As stated in the paper and as noted from examination of micrographs 11, 12 and 13, only the fine "matrix" carbides go into solution. The larger or "eutectic" carbides are not affected by this treatment. We wish to emphasize then that only a portion of the carbon present in alloy 57 goes into solution in the alpha iron. The exact amount of carbon soluble in this alpha iron at 1300 degrees Fahr. has not been accurately determined at this time of writing. Some preliminary tests, however, have been made. Weighed samples in each of the conditions as shown in micrographs 11, 12 and 13, were exposed to attack by dilute cold hydrochloric acid until solution was complete. It was noted that the samples represented by micrographs 11 and 13 were readily attacked and dissolved considerably faster than the sample represented by micrograph 12. The per cent weight of carbide residue based on the weight of original sample was as follows:

Steel represented by micrograph 11—per cent weight 8.5

Steel represented by micrograph 12—per cent weight 0.7

Steel represented by micrograph 13—per cent weight 1.2

More detailed experiments are now being made but to date there is nothing further to report.

In the third paragraph, Mr. Griffiths suggests that the precipitation of nitrides is the most probable explanation of this unusual phenomenon.

The nitrogen content of steel 57 was determined as 0.015 per cent. This amount is about normal for steels made in a small electric furnace, and the authors do not believe this percentage of nitrogen is sufficient to explain the changes in hardness. If nitrogen were the determining factor, then other steels made the same way and containing the same amount of nitrogen would show the same phenomenon. However, we find this is not the case. In the last paragraph of Mr. Griffiths' discussion it is also suggested that a new phase or constituent similar to the "B" constituent described in Bain and Griffiths' paper entitled "An Introduction to the Chromium-Iron-Nickel Series", may be responsible for the unusual increase in hardness. On the fourth page of Bain and Griffiths' paper, the "B" constituent is defined as follows:

- (a) Massive form—a clear etching, corundum-hard, brittle, non-magnetic constituent, usually filled with faint cracks.
- (b) Troostitic form—dark etching, solid dispersion of sub-microscopic particles of true "B" constituent in various amounts of ferrite matrix. Weakly magnetic, hard, and often cracked. An intermediate form in ferrite changing to "B" constituent by long time heating at low temperature.

The fact that alloy 57 in all three conditions as represented by micrographs 11, 12 and 13, is fully magnetic, would eliminate the possibility of the massive form of "B" constituent. The troostitic form of "B" constituent resembles steel 57 in the condition shown in Fig. 11. However, in this condition the alloy is soft and in the stable low temperature form. These properties do not conform to the characteristics of troostitic "B" constituent, thus making this explanation also improbable.

The authors thank Mr. Charlton for his interesting and complete discussion. His observations on the refining action of nickel and tungsten are in accord with the authors' results. The reference to tensile strength at elevated temperatures is interesting. All the values given in this paper were taken from annealed samples. Mr. Charlton's report indicates that heat treatment will improve these values, thus adding to the desirable qualities of chromium-aluminum steels.

Mention is also made of a new series of aluminum steels containing 1 per cent carbon, 18 per cent chromium and 2 per cent aluminum. This analysis is familiar to the authors and considerable data has been obtained. For certain purposes these high chromium steels are superior to the lower chromium high aluminum alloys reported in this paper.

PROGRESS MADE IN THE USE OF ELECTRIC FURNACES FOR HEAT TREATING

BY A. N. OTIS

Abstract

The object of the paper is to show the present status of electric furnaces, the extent of their use for heat treating, and some new types that have been recently developed.

The development of electric furnaces is briefly reviewed and their advantages for heat treating are pointed out.

The rapid increase in the use of electric furnaces is shown by a list of the principal installations, describing briefly some of the individual furnaces and their operation. Photographs are shown to illustrate the various types. Reference is made to specific applications, including furnaces for annealing tool steel bars and rods, and elevator furnaces for annealing sheet steel for electrical machines, the latter without the use of boxes. Large savings are shown by this method.

Among new developments, electric furnaces for forging are referred to, also continuous furnaces for the new process of copper brazing, and for annealing in atmospheres of protecting gas.

THE remarkable increase in the efficiency of manufacturing operations during recent years has frequently been made the subject of comment, and the application of scientific knowledge to the problems of industry is recognized as an important factor in this progress. Metallurgists have made outstanding contributions by intensive studies of the characteristics of metals and alloys, which have not only revealed new facts regarding the metals themselves, but have shown that materials with entirely new properties can be produced by proper manipulation and treatment. As a result, industry now has at its disposal a series of steels and other materials having the special properties required

A paper presented before the tenth annual convention of the society held in Philadelphia, October 8 to 12, 1928. The author, A. N. Otis, a member of the society, is associated with the industrial heating and welding engineering department, General Electric Co., Schenectady, N. Y. Manuscript received July 2, 1928.

for high speed cutting tools, for forging and stamping dies, etc., and also materials for fabrication into products or machines that will give long wearing life in severe and sustained service.

Such materials and such machines have made it possible for workmen in all lines of industry to produce goods in quantity and of quality that would have been considered fantastic a comparatively few years ago.

The exacting work of the metallurgists required care in the preparation and treatment of their materials, and it is significant they have used electric furnaces in their laboratories, as a means of securing accurate temperature control of the heating processes, and of avoiding contamination of the materials under treatment. It was however quite impracticable to reproduce these conditions in the factory, and this fact operated to prevent industry from taking full advantage of the scientific developments in heat treatment.

The electric furnace, therefore, was of great value as a means of securing scientific data upon which the heat treatment of metals is based, and it was only a question of time until it would find its place as an instrument of production as well as of research.

The enormous increase in the use of heat treated products will be appreciated when it is recalled that twenty-five years ago the art of heat treating was a secret, known to relatively few workmen, while today it is represented by this society with its thousands of members. Also by recalling that the earlier automobiles had few if any heat treated parts, compared to the automobiles of today, in which all parts subjected to severe shock, stress or wear are heat treated.

Uniformity of treatment and expeditious handling are important considerations in volume production, and many types of furnaces have been developed to meet the requirements. Some of these furnaces, together with their auxiliary equipment, are fully automatic in their operation, both as regards temperature control and mechanism for carrying the work through. They are in fact automatic heat treating machines, and represent a state of advanced engineering comparable to the advances made in other lines.

The increase in the use of electric furnaces since 1920, when they became recognized as an important industrial tool, has been

phenomenal. It is true that the preliminary work had been done, and the way had been paved to commercial applications, by the results of operating many of these furnaces during the war

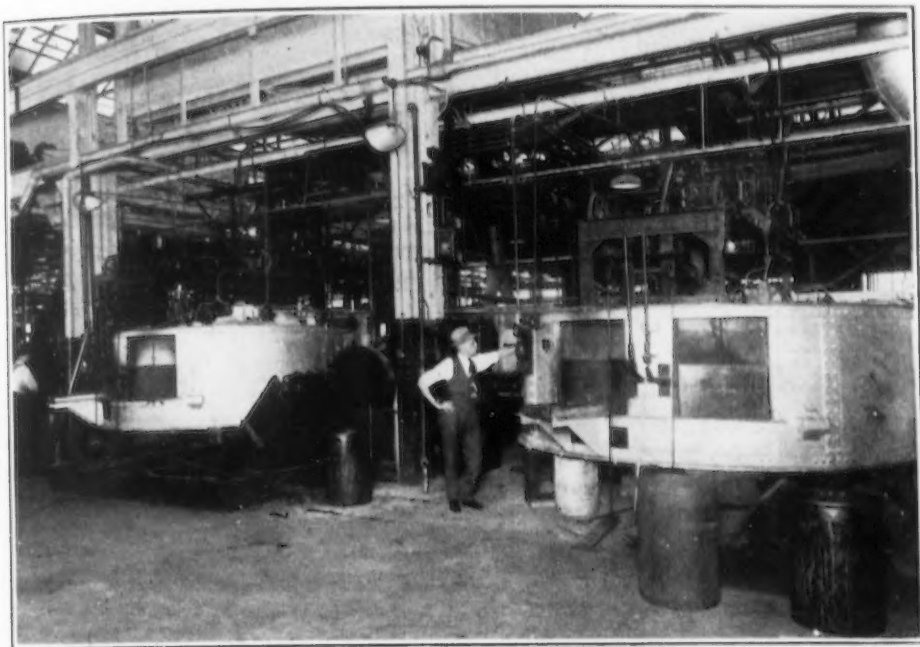


Fig. 1—Typical Rotary Hearth Furnaces with Tipping Trays for Automatic Quenching.

period for the heat treatment of gun forgings, but their reliability and economy in competitive industry had yet to be demonstrated.

These facts were demonstrated in due course, in one industry after another, with the result that there are hundreds of electric furnaces in operation today for annealing brass and copper, vitreous enamelling, etc., as well as for heat treating.

The advent of the electric furnace into the industrial field as an aggressive competitor of fuel-fired furnaces has exerted a decided influence on the design of all furnace equipments. For example, automatic temperature control was unknown until it was developed for use with electric furnaces, and it is now considered a prime requisite of heat treating furnaces of whatever type. Also, improved design in many ways has resulted from efforts to equal the performance of electric furnaces.

Furnace users generally, therefore, have received the benefits of improved equipment of every type. Modern electric fur-

naces are readily adaptable to special forms or designs of hearths and carriers to meet unusual requirements, and the fact that they can be located at the most advantageous point and fitted into the production scheme like other machines, are important advantages in speeding up production, reducing the cost of handling and in-



Fig. 2—Typical Pusher Furnaces for Hardening Gears and Other Parts.

creasing turn-over. They leave little to be desired in the way of operating characteristics or adaptability, and a discussion of the choice of furnaces will finally center about the cost of heat.

In any particular case, the cost of heat can be accurately predicted under the contemplated conditions of operation, and is a fairly simple matter. It remains, however, to balance this against the incidental economies and advantages procurable with the various types of furnaces under consideration, which is not so simple. The mistake should not be made of reaching a conclusion on the basis of cost of heat alone, or of any other single item, but all factors having a bearing on the problem should be given due consideration.

The manufacturer's object is to produce the highest quality product at the lowest cost, and heating operations should be viewed as a part of the whole process, rather than merely the economical use of fuel in a furnace. The use of electric furnaces,

for example, may permit a complete rearrangement of manufacturing facilities, or in other ways make possible economies that are many times greater than the cost of heat.

The cost of heat for most products is about one per cent of their value. The difference between fuel and electric heating, if there is a difference, will be so small in the average case as



Fig. 3—Typical Pusher Type Counterflow Annealing Furnaces.

to have no appreciable effect on the production cost. This difference would easily be outweighed by any reduction in the number of rejects or retreats, greater uniformity, permitting higher speed of cutting operations, lower labor cost, facility in handling materials or other savings of rearrangement. These incidental factors are quite as important as the cost of heat, although they cannot be as readily obtained for comparison.

The actual cost of heat in some applications is less with electricity than with fuels. This is particularly true where long heat cycles are necessary and losses are a large part of the total heat requirements, or where surplus material must be heated such as annealing pots, that can be eliminated with electric furnaces.

In the latter case the economies come not only from the direct saving in pots, but from the heat to heat them, and the saving in time, which results in greatly increased output from equipment that can operate without them. This subject is discussed in

detail later, with special reference to annealing sheet steel strips and punchings for electrical machines.

That electric furnaces have been found economical, is shown by their extensive and increasing use in many large manufacturing plants, and in order to show the growth and the status of



Fig. 4—Group of Four-track Pusher-type Carburizing Furnaces.

electric furnaces at the present time, a list of some of the principal installations of furnaces used for heat treating has been prepared. Some of these installations have been described in published articles from time to time, but a list that will give a more comprehensive survey may be of interest and possibly have some historical value in the future.

Many of these plants started with one or two electric furnaces for trial or for some special purpose, and have continually added to them.

In addition to the installations listed, there are many others having one or several furnaces of various types, also hundreds of smaller box-type and cylindrical furnaces, lead and cyanide pots, tempering furnaces, etc., which it would be impossible to enumerate here, but which, nevertheless, form a large and important group of furnace users.

FURNACES FOR GENERAL HEAT TREATING

Plant No. 1—Automobile Parts

The electric furnace equipment in this plant consists of the following:

- 2—Rotary hearth furnaces, 24-inch hearth width, 175 kilowatts each. Hearth arranged with tipping trays to discharge contents directly into quench. Each has two temperature control zones, one operated at 1600 degrees Fahr. for normalizing. Output 1700 pounds per hour at 11.2 pounds per kilowatt hour. The other is operated at 1200 degrees Fahr. for tempering. Both operate automatically by time clocks.
 - 1—Four-track counterflow pusher furnace for carburizing; 42-foot working length; Chambers 2 feet 5 inches wide; 90 kilowatts in each of the 4 chambers. Two control zones in each chamber. Insulated division wall lengthwise divides furnace into two separate units, either one of which may be used while the other is idle if desired.
- Four different time cycles and operating temperatures may be used in furnace of this type.
- Output 2700 pounds per hour gross at 13.5 pounds per kilowatt hour. Time cycle 18 hours. Average net 4.35 pounds per kilowatt hour.
- 5—Cyanide and lead pots 18 inches in diameter—30 kilowatts.

Plant No. 2—Automobiles

The equipment in this factory includes the following:

- 32—Box furnaces $5\frac{1}{2}$ feet wide, $8\frac{1}{2}$ feet long, built in 8 groups of 4. Door at each end of chamber. Used for hardening, tempering and annealing forgings. 155 kilowatts each. Charges 1000 pounds. Loaded by charging machine. Pushed through to quench tanks. Average time in furnace 1 hour, output 1000 pounds per hour at 10 pounds per kilowatt hour. Every piece inspected for hardness. Retreats one per cent.
 - 6—Pusher furnaces $5\frac{1}{2}$ feet wide, 15 feet long for annealing and tempering forgings. Each has 3 tracks. Material carried through on trays or stools.
- Operate automatically by time clocks. Interval adjustable for different size forgings.
- 1—Double chamber pusher furnace for a special normalizing treatment of alloy steel ring gear forgings. Heat to 1650 degrees Fahr. hold definite time. Cool in definite time to 1320 degrees Fahr. hold a definite time at this temperature, then slowly cool. The cycle requires 9 hours. Radiators built into the furnace and cooled by air from a blower, drops temperature from 1650 to 1320 degrees Fahr. in 40 minutes. Flow of air is regulated by automatic control of valves from a temperature control instrument.

Furnace 45 feet long by 40 inches wide. Work put through in trays 36 by 12 inches. Discharge end of one chamber is beside loading end of other chamber. Saves transporting trays. They are simply circulated through the furnaces. Pans are hot when loaded, saving the stored heat.

3—Rotary furnaces for carburizing. Inside diameter hearth 12 feet, outside diameter 22½ feet. Capacity each furnace 500 kilowatts divided



Fig. 5—Vertical Pusher Furnaces for Hardening Ring Gears.

into three temperature control zones. Parts quenched from the box. The three furnaces produce approximately 1,000,000 pounds of carburized parts per month.

6—Two-track counter flow pusher furnaces for carburizing 48½ feet long, each chamber 36 inches wide, 110 kilowatts in each chamber, divided into two temperature control zones.

5—Rotary furnaces for hardening gears. Hearth diameter 10½ feet, width 18 inches. The parts from these furnaces are dipped in cyanide for a brief interval before quenching. Cyanide pots referred to later.

1—Rotary furnace, 18-inch wide hearth, 135 kilowatts for normalizing flywheel starter ring gear blanks and for hardening the finished gear.

1—Rotary furnace, 12-inch wide hearth for brazing.

2—Roller hearth furnaces for hardening ring gears, each having two chambers one above the other. Chambers 9 feet long, 24 inches wide. Each furnace heats 50 gears per hour.

5—Cyanide pots 18 inches in diameter, 30 kilowatts each.

Plant No. 3—Automobiles

This manufacturing plant has the following electric furnace installations:

- 4—Pusher-type carburizing furnaces. Each has 4 tracks heated the full length (not counterflow), 440 kilowatts each. Parts quenched from the box. Used for ring gears; 10 gears per box, 12 boxes per hour per furnace; 11 hours in furnace. Automatic operation by time clocks.
- 4—Pusher-type counterflow normalizing furnace for miscellaneous forgings; 25 feet long, 5 feet wide, 170 kilowatts. Output 1750 pounds per hour. Work carried on trays; $4\frac{1}{2}$ hours in furnace; $14\frac{1}{2}$ pounds per kilowatt hour.
- 3—Pusher-type furnaces for hardening differential gears, drive pinions, etc., 110 kilowatts each.
- 3—Pusher furnaces smaller size; 50 kilowatts each for hardening small parts.
- 8—Vertical pusher furnaces for hardening ring gears, quenched in Gleason machines. 65 kilowatts each. 60 gears each per hour. 10 pounds per kilowatt hour.
- 6—Vertical tempering furnaces. 24 inches in diameter with circulating air.

Plant No. 4—Automobiles

This automobile plant is equipped with the following electric furnace equipment:

- 6—Four-track counterflow pusher furnaces for carburizing 30 feet long. Three temperature control zones. Two are used for smaller gears and connecting rod pins, etc. Two are used for cam shafts. One is used for ring gears. One for differential gears and other small parts. Boxes in furnace 25 to 33 hours. Round boxes for ring gears—long boxes for cam shafts.
- 2—Pusher furnaces for hardening cam shafts.
- 2—Pusher furnaces for hardening connecting rods.
- 1—Pusher furnace for tempering connecting rods.
- 2—Counterflow pusher furnaces for annealing small iron castings. Heated to 1300 degrees Fahr. Output 1300 pounds per hour for each furnace. Material in furnace 4 hours, about $1\frac{1}{2}$ hours in hot zone. One man at each end loads and unloads both furnaces.
- 2—Pusher furnaces for hardening axle shafts. Automatic quench.
- 1—Pusher furnace for tempering axle shafts, 1000 degrees Fahr. Sent through two rows high on carriers. Tempers axles hardened in above 2 furnaces.
- 1—Small pusher furnace with 3 rows of trays for hardening piston pins, tappet rollers and small parts.
- 4—Small continuous furnaces, for hardening shackle bolts. Parts are supported in notches of fish-bone strips. Strips pulled through

by traction wheels at discharge end. Single row. Capacity 220 per hour.

2—Larger furnaces similar to above. Two rows 450 to 600 per hour.

2—Small pusher furnaces for king bolts. Capacity 225 per hour. Fifteen rows of pins laid lengthwise with hearth pushed one at a time by cam mechanism.

1—Rotary hearth furnace 6 feet in diameter hearth, for differential gears, pinions, etc. 70 kilowatts. 400 to 500 pounds per hour.

2—Rotary hearth furnaces. Hearth 3 feet wide, 14 feet outside diam.

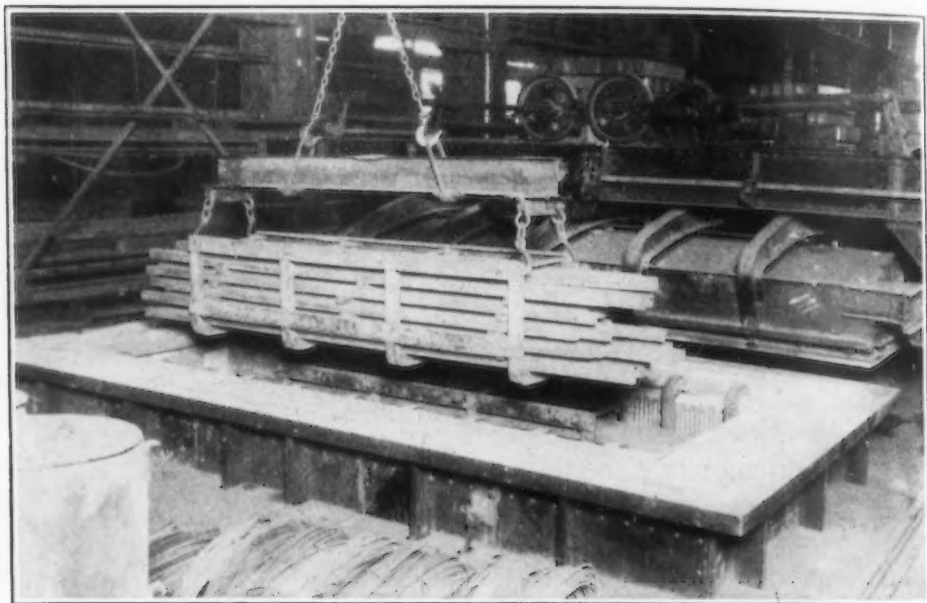


Fig. 6—Pit-type Furnace for Annealing Roller Bearing Stock.

eter, three control zones, 250 kilowatts for normalizing forged blanks for ring gears and drive pinions. One operates at 1600, the other at 1300 degrees Fahr. 1800 to 1900 pounds per hour output.

2—Rotary hearth furnaces, duplicates of above, for front axle parts, arms, spindles, etc., one operates at 1500, other at 1300 degrees Fahr.

Plant No. 5—Automobiles

This plant has the following electric furnace equipment used in heat treating the various parts of the car. They are as follows:

1—Roller hearth furnace for hardening transmission and differential gears. 13 feet long, 18 inches wide, 861 kilowatts. Two temperature control zones. Work goes through on skeleton racks with pins. Output 760 pounds per hour gross, 550 pounds net.

2—Vertical pusher furnaces for hardening ring gears—quenched in Gleason Machine, each 60 gears per hour.

3—Pusher type furnaces for annealing, hardening and tempering axles.

290 kilowatts in hardening and annealing furnaces, 190 kilowatts in tempering furnace.

- 1—Double chamber pusher furnace for normalizing forged gear blanks, 42 feet long. 285 kilowatts and 5 temperature control zones in each chamber. Seven-hour time cycle. Held at temperature for definite time, cooled by radiators at definite rate to a lower temperature and held for definite time, then slowly cooled.
- 1—Pusher type, 4-row carburizing furnace 49 feet long. 240 kilowatts for piston pins and other small parts.

Plant No. 6—Automobile Parts

The electric furnace equipment in this plant consists of the following:

- 1—Car-type furnace 9 feet long, 3 feet wide for hardening and annealing large die blocks of air quenching steel. Blocks 4500 pounds each, two per load, temperature 1600 degrees Fahr.
- 2—Large rotary hearth furnaces for hardening and tempering crank shafts.

Hardening, quench and temper are fully automatic by time clock. Man puts parts on loading platform only. Shafts of many different sizes are handled. Output 6000 to 7000 pounds per hour. Over 3½ million pounds have been treated per month. Parts delivered automatically from tempering furnace to straightening press. Mean diameter of hearth 23½ feet. Outside diameter of shell 32 feet. Hardening furnace 793 kilowatts, tempering furnace 720 kilowatts.

Plant No. 7—Excavating Machinery

This factory, manufacturing excavating machinery, has the following electric furnace installation used in the heat treatment of parts:

- 4—Box-type furnaces, hearths 5 feet by 6½ feet for heat treating steel castings, arranged with quenching tanks, loading platforms and charging machine for expeditious handling of material. Charges 1000 to 4000 pounds.
- 1—Car-type furnace 14 by 3 feet for large castings, shafts and forgings.

Plant No. 8—Tractors

This plant manufacturing tractors has the following electric furnace installations:

- 1—Rotary with 3-foot wide hearth, 195 kilowatts.
- 1—Rotary with 2-foot wide hearth, 165 kilowatts.
- 2—Pusher type normalizing furnaces, 175 kilowatts each.
- 2—Rotary with 5-foot wide hearth, 150 kilowatts for heat treating crank shafts.
- 1—Roller hearth furnace for hardening gears.

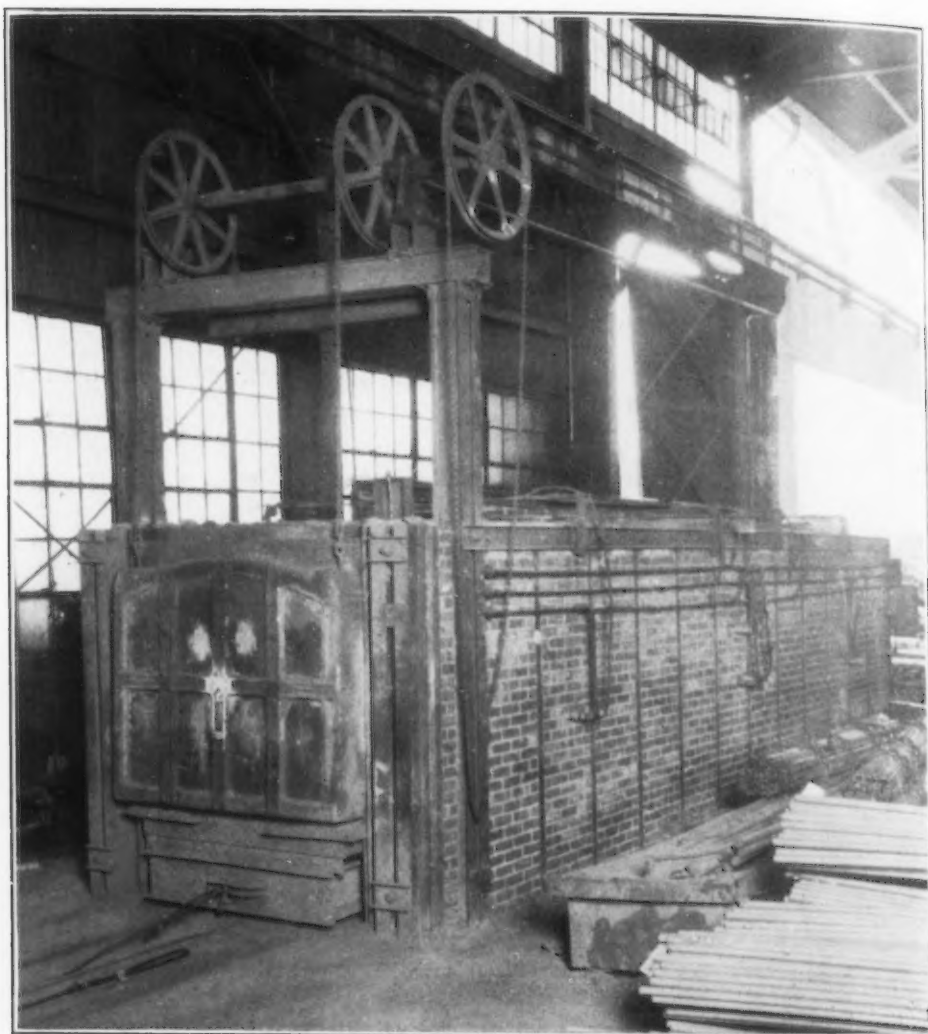


Fig. 7—Car-type Furnace for Annealing Alloy Steel Bar Stock.

Plant No. 9—Agricultural Implements

In the manufacture of agricultural implements, this plant has the following electric furnace equipment:

- 4—Rotary with 2-foot wide hearth, 155 kilowatts each.
- 4—Pusher furnaces, 75 kilowatts each.
- 1—Pusher furnace, 150 kilowatts each.
- 1—Four-track pusher carburizing furnace, 355 kilowatts.
- 1—Pusher type furnace for shrinking, 35 kilowatts.

Plant No. 10—Agricultural Implements

This agricultural implement plant has the following electric furnace installation:

- 1—3-chamber, 6-track counterflow carburizing furnace 46 feet long.
- 1—2-chamber counterflow furnace, 7 feet wide for carburizing large gears in boxes 3 feet wide.
- 1—2-chamber furnace similar to above 45 inches wide.

Plant No. 11—Tractors

In the manufacture of tractors this plant has the following electric furnace equipment:

- 3—Box furnaces 5 feet long, $4\frac{1}{2}$ feet wide for annealing tractor parts. Cooling chamber at one end, 120 kilowatts each.
- 3—Pusher tempering furnaces. 12 feet long, 4 feet wide, with 3 tracks, 80 kilowatts for tractor parts.
- 5—Rotary hearth furnaces, 3-100 kilowatts and 2-120 kilowatts for hardening.
- 1—Pusher hardening furnace 20 feet long, 24 inches wide, 120 kilowatts.

Plant No. 12—Automobiles

This concern manufacturing automobiles is equipped with the following electric furnaces:

- 1—Rotary hearth furnace with 3-foot wide hearth, 175 kilowatts with 2 control zones.
- 1—Rotary hearth furnace—2-foot wide hearth, 175 kilowatts arranged with tipping trays to automatically discharge parts. Two control zones.
- 2—Box-type 7 feet long, $3\frac{1}{2}$ feet wide. Flat hearth for annealing miscellaneous parts, 95 kilowatts each.
- 3—3-chamber, 6-track counterflow carburizing furnaces 50 feet long inside, each chamber 4 feet wide.

Plant No. 13—Automobiles

Another automobile plant has the following electric furnace equipment:

- 1—Rotary with 5-foot wide hearth, 325 kilowatts.
- 1—Rotary with 3-foot wide hearth, 150 kilowatts.
- 1—Rotary with 2-foot wide hearth, 125 kilowatts.
- 1—Rotary with 18-foot wide hearth, 130 kilowatts.
- 1—Rotary with 18-foot wide hearth, 80 kilowatts.
- 2—Box-type, 7 feet long, $3\frac{1}{2}$ feet wide, 95 kilowatts each.

Plant No. 14—Automobiles

Still another automobile plant has the following electric furnace installation:

- 1—Rotary with 3-foot wide hearth, 150 kilowatts.
- 1—Rotary with 2-foot wide hearth, 125 kilowatts.
- 4—Box-type, 7 feet long, $3\frac{1}{2}$ feet wide, 95 kilowatts each.

1—3-chamber, 6-track counterflow furnace, 540 kilowatts, 46 feet long for annealing and carburizing.

Plant No. 15—Ball Bearings

In the manufacture of ball bearings this plant has the following equipment:

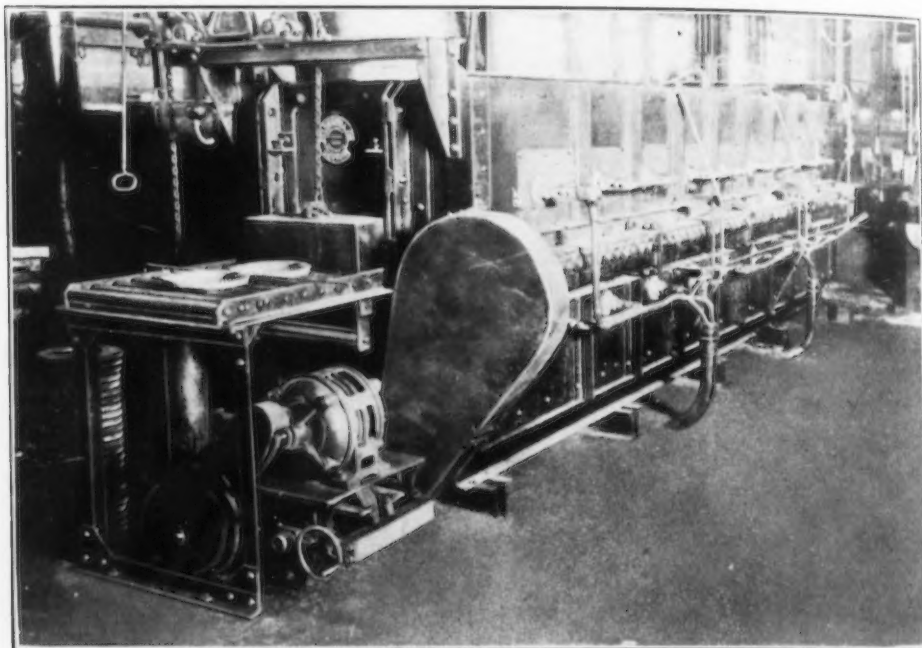


Fig. 8—Roller Hearth Furnace for Hardening Ring Gears.

8—Car-type furnaces, $11\frac{1}{2}$ feet by $3\frac{1}{2}$ feet, 150 kilowatts each for annealing forgings for bearing races.

Plant No. 16—Textile Machinery

This plant has the following electric furnace installation:

8—Box-type furnaces 6 feet by 5 feet, 76 kilowatts for annealing and carburizing parts for textile machinery.

Plant No. 17—Sewing Machines

In the manufacturing of sewing machines this plant has the following electric furnace equipment:

3—Car-type furnaces, 14 feet by 7 feet for annealing coiled wire and strip in pots.

Plant No. 18—Steel Furniture and Building Equipment

This concern manufacturing steel furniture and building equipment has the following electric furnace equipment:

- 2—Box-type furnaces 11 feet by 4 feet for carburizing guard bars for banks, jails, etc.
- 2—Similar furnaces 9 feet by 4 feet.

Plant No. 19—Motor Trucks

In the manufacture of motor trucks, this plant has the following electric furnace installation:

- 8—Box-type furnaces 8 feet by 4 feet for carburizing parts for motor trucks.

Plant No. 20—Steel Castings

In the annealing of steel castings this plant has the following electric furnace equipment:

- 1—Car-type furnace 12 feet by 5½ feet, 250 kilowatts for annealing steel castings. With heating and cooling chamber and motor driven transfer table. Charge 10 to 12 tons, two heats per day.

Plant No. 21—Steel Castings

- 1—Car-type furnace—duplicate of above.

Plant No. 22—Chemical Plant Equipment

This concern manufacturing chemical plant equipment has the following electric furnace installation:

- 1—Pit-type furnace 33 feet long, 6½ feet deep, 2 feet wide, 900 kilowatts, 1600 degrees Fahr. for heating heavy steel plates on edge, preparatory to rolling into large pressure vessels.
- 1—Car-type furnace 68 feet long, 12 feet wide by 12 feet high, 3000 kilowatts, 1200 degrees Fahr. for relieving welding strains in large pressure vessels. Load 200 to 300 tons. Cools in the furnace. Twenty-two vessels have been annealed per month.

Plant No. 23—Electrical Apparatus

This company manufacturing electrical apparatus uses the following electric furnace equipment in their manufacturing operations:

- 1—Group of furnaces for heat treating gears and pinions for railway motors, consisting of:
 - 1—Box-type, 7 feet by 4½ feet, for hardening, 105 kilowatts.
 - 1—Box-type, 5 feet by 2½ feet, for hardening, 60 kilowatts.
 - 1—Vertical cylindrical for tempering gears.
 - 1—Rotary hearth for tempering pinions.
- 1—Car furnace, 17 feet by 6½ feet, 240 kilowatts for heat treating forgings for turbine wheels, shafts, etc.
- 1—Car furnace, 27½ feet by 16 feet by 9 feet high, 620 kilowatts, 1000 degrees Fahr. for annealing large iron castings for turbines.

- 2—Car furnaces, 20 feet by 15 feet by 9 feet high, 1000 kilowatts, 1600 degrees Fahr. for annealing large steel castings for turbines.
- 2—Box furnaces, 8 feet by 8 feet, 200 kilowatts, for treating forged rings for turbo-generators.
- 3—Box furnaces, 6 feet by 6 feet, 115 kilowatts, for heat treating turbine bucket stock.

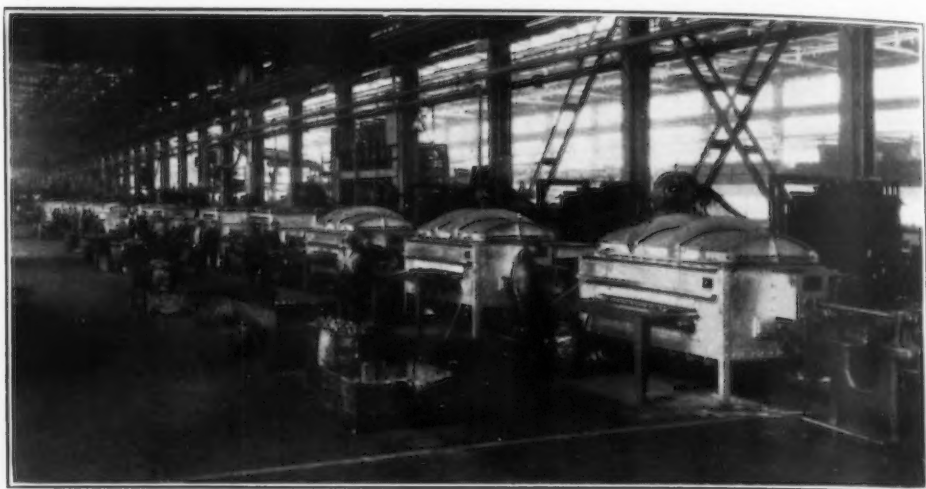


Fig. 9—Group of Electric Furnaces for Forging.

- 3—Box furnaces, 7 feet by 4½ feet, 105 kilowatts, for carburizing and annealing.
- 25—Elevator-type furnaces of various sizes for annealing sheet steel and punchings (referred to elsewhere).
- 8—Brazing furnaces of various types and sizes for assembling parts by the copper brazing process (referred to elsewhere).
- 15—Box-type furnaces of various sizes for dies, tools, molds, etc.

Plant No. 24—Roller Bearings

In the manufacture of roller bearings this company uses the following electric furnace equipment:

- 2—Rectangular pit furnaces 21 feet long, 9 feet wide, 6½ feet deep, 850 kilowatts each, for annealing bars of alloy steel. Will take charges of 40 to 50 tons. Cooling coils are built into the furnace to accelerate cooling after critical range has been passed. Air forced through the coils by blowers.
- 1—Longitudinal and cross pusher furnace 21 feet long, 12 feet wide, 700 kilowatts for normalizing bars before annealing. One mechanism pushes bars into the furnace, another pushes them across and another pushes them out. Will handle bars up to 5 inches square. Output 150,000 pounds per day. Power consumed 200 kilowatt hours per ton.
- 1—Pusher-type hardening furnace 20 feet long, 6 feet wide, 300 kilowatts

1929

for hardening bar and tube stock: Bars pushed in from rear end and pushed through when heated to a tilting table which dumps it into the quench.

2—Cylindrical pit furnaces 100 kilowatts each for annealing small rods in coils.

1—Car furnace 20 feet long, 6 feet wide, 300 kilowatts for annealing bar stock, 10 to 15 tons per charge.

1—Car furnace 28 feet long, $4\frac{1}{2}$ feet wide, 460 kilowatts for annealing bar stock, 15 to 20 tons per charge.

Probably the largest electric furnace installation anywhere is at the Fordson plant of the Ford Motor Company. There are 145 furnaces at this plant used for a wide variety of work, such as heat treatment and forming of spring leaves, heat treatment of crank shafts, connecting rods, gears and other parts, and heating stock for forging. There are 115 furnaces in one building, the spring and upset department:

76 for heat treating and forming springs

28 for forging gear blanks and similar parts

6 pusher furnaces for annealing, hardening and tempering

5 for tools, dies and small parts.

The furnaces for hardening and tempering springs are equipped with slat conveyors and are operated at about 1500 and 875 degrees Fahr. respectively. When removed from the hardening furnace the leaves are clamped in a quenching fixture which forms and holds them to the desired shape.

Perhaps the most interesting are the furnaces for heating the ends of the long spring leaves, for forming the eyes which engage the shackle bolts. These furnaces are arranged in pairs, a conveyor running between them so that both ends are heated simultaneously. The temperature is 2000 degrees Fahr. Emerging from the furnace they are placed in a forming machine which curls both ends at one operation. In each of the units leaves are heated and curled at the rate of 8 per minute. The furnaces in this department are capable of handling 6000 rear springs, 12,000 front springs and 2500 springs for the truck in two eight-hour shifts.

The forging furnaces are a recent development. A row of them is shown in Fig. 9. The absence of smoke, excessive heat and gases is a very desirable feature which not only permits the furnaces to be located at the most advantageous points for the routing of the material but also provides the best possible

conditions for these employees, so that they can work at maximum efficiency.

The furnaces operate at 2350 degrees Fahr. and are automatically controlled, which insures against burnt or overheated forgings, another valuable feature. About 700 pounds of forgings are produced per hour from each furnace, and the yield is about 4 pounds per kilowatt hour. Such furnaces may be used extensively in the future for light forging work and other operations which require these temperatures.

The continuous annealing furnaces are of the four-track counterflow pusher-type, alternate rows moving in opposite directions.

There are 19 furnaces of different types in the Motors building. Three of these are continuous pusher furnaces, 24 feet long for hardening crankshafts. In order to save floor space the tempering furnaces are built on top of the hardening furnaces, with the entrance just above the discharge opening of the hardening furnaces. They are of the chain conveyor-type, the finished work returning to the entrance end where it is unloaded. Each unit has capacity to harden and temper 95 crankshafts per hour.

Other furnaces in this building include:

- 3—Pusher furnaces for hardening connecting rods
- 3—Pusher furnaces for tempering connecting rods
- 3—Pusher furnaces 42 feet long for tempering gears
- 2—Rotary furnaces 14 feet diameter for hardening cam shafts
- 2—Continuous furnaces for piston pins, push rods, etc.

In the rolling mill there are two continuous furnaces for heating bar steel for forming ring gears, 300 and 400 kilowatts respectively, operating at 2000 degrees Fahr., six forging furnaces, operating at 2350 degrees Fahr., and totalling 2700 kilowatts, also three continuous hardening furnaces of 300 kilowatts each.

The number and diversity of applications in this plant alone, shows the adaptability of electric furnaces to many forms and purposes.

ANNEALING TOOL STEEL BARS AND RODS

Electric furnaces have come into quite general use for annealing tool steel bars and rods, and a number of manufacturers of this material are now using electric furnaces exclusively for annealing.

Slow cooling is required and the material is placed in covered

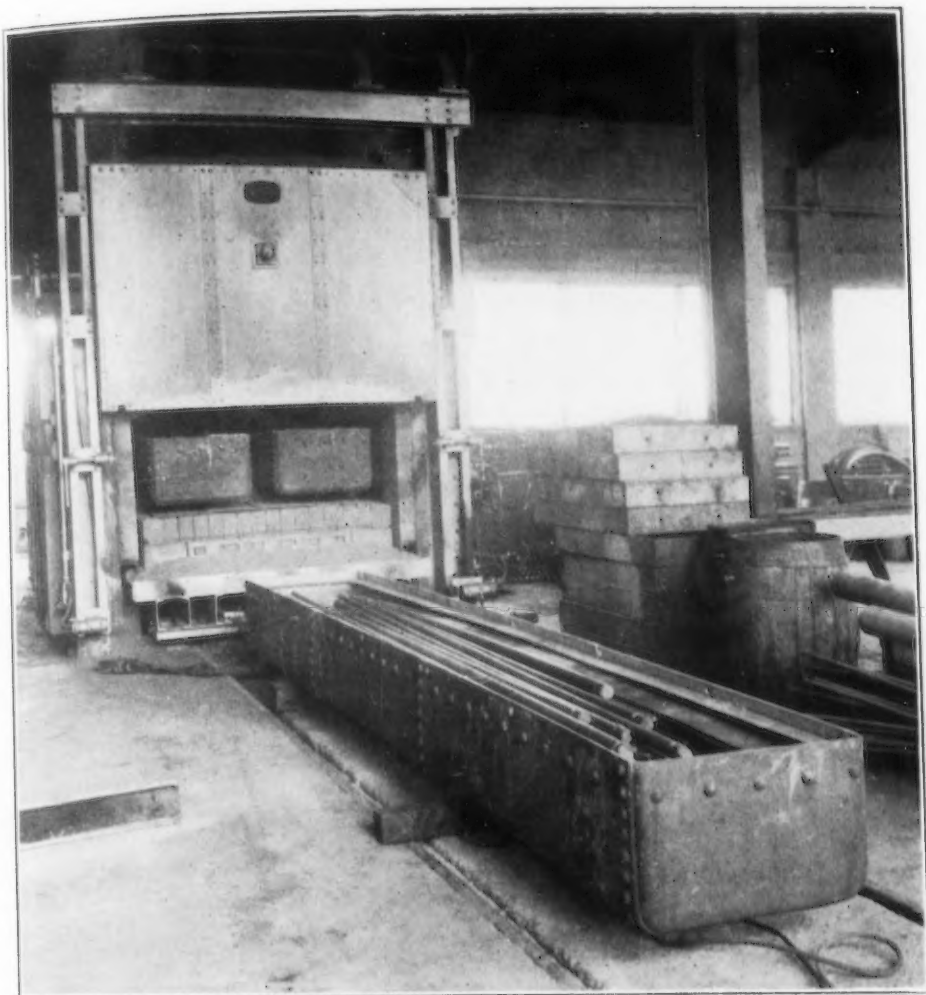


Fig. 10—Car-type Furnace for Annealing Tool Steel Bars in Boxes.

boxes in order to prevent decarburization during the long cycle, which is usually about 48 hours total. Five tons is the usual box load. These furnaces are of the car-type, $2\frac{1}{2}$ to 6 feet wide and 16 to 20 feet long, depending on whether designed for one box or two boxes per load. The connected capacity is 120 to 350 kilowatts. A typical furnace with a loaded box in front to give more detail is shown in Fig. 10. Temperatures of 1450 to 1650 degrees Fahr. are required for various kinds of stock.

The heating and holding time is 15 to 24 hours, and cooling time 20 to 30 hours. Three heats per week are usually obtained. The power consumed is 370 kilowatt hours per net ton annealed under good conditions, that is when in continuous operation and

the furnaces charged while still warm, 800 to 900 degrees Fahr.

A furnace designed for two boxes or a load of 10 tons will anneal 1600 tons per year, and the total cost of annealing, including power, boxes, labor and capital charges is approximately \$10.00 per net ton. This may be segregated as follows, allowing 6 per cent interest on \$10,000, the approximate cost of equipment and 10 per cent depreciation.

Power—400 kilowatt hours @ $1\frac{1}{2}$ c	\$6.00
Boxes	0.65
Labor, use of crane and overhead	2.20
Interest on investment and depreciation @ 16 per cent	1.00
Total	\$9.85

The advantage of electric furnaces for this purpose lies in the uniformity of the annealed product, and the fact that no labor for attendance is required for the heating operation.

Re-anneals to meet the requirements of careful inspection will run from zero to 1 per cent. To pass the same inspection, material from fuel-fired furnaces is said to require a considerably higher percentage of re-anneals. At least sixteen furnaces of this type are in use at 8 different manufacturing plants, and it is estimated that over 50 per cent of the tool steel produced today is annealed in electric furnaces.

Plant No.	No. of Furnaces
1	3
2	1
3	1
4	2
5	1
6	1
7	1
8	6

One of the manufacturers uses boxes made of alloy plate. Examination of these shows that little or no scale or distortion has taken place after three years use, and apparently these boxes are good for many more years of service. This is due in part at least to the uniformity of temperature in the electric furnace, the absence of hot spots, and less chemical action of the atmosphere.

Further experience may show that the cost of boxes given in the tabulation may be considerably reduced by the use of heat resisting materials.

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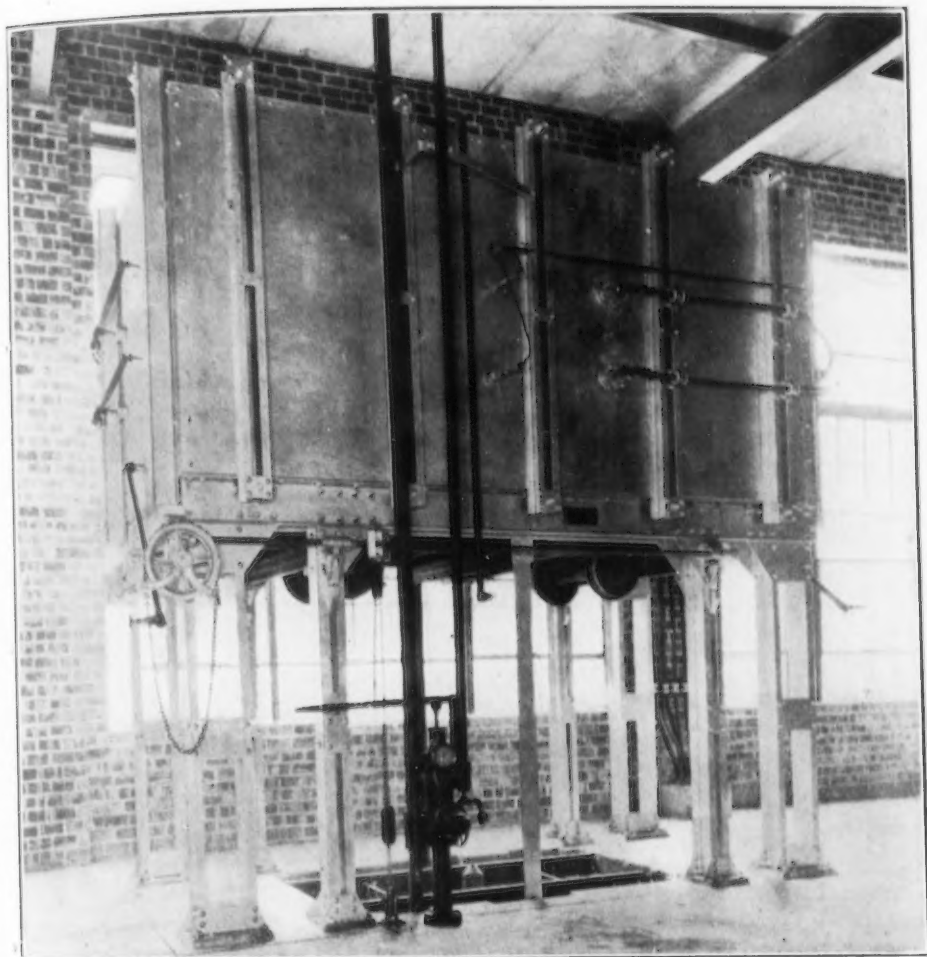


Fig. 11—Elevator-type Furnace.

ELEVATOR TYPE FURNACES FOR ANNEALING

The elevator-type furnace is particularly well adapted for annealing steel products in large quantities and are used for such materials as sheets and punchings for electrical machines, disk wheels for automobiles, gear blanks and castings.

These furnaces consist of a chamber with the opening at the bottom, mounted on legs at an elevation above the floor, and a car arranged to be run in under the furnace on a platform and to be raised into position by a hydraulic cylinder or other suitable means. Seals around the edge of the car and a tightly welded casing are quite effective in excluding air from the heating

chamber, and makes the use of an artificial atmosphere practicable if desired.

A furnace of this type is shown in detail by Fig. 11 and a group of them used for sheet steel is shown by Fig. 12.

One of the advantages attending the use of these furnaces is the elimination of the boxes or containers formerly used with fuel-

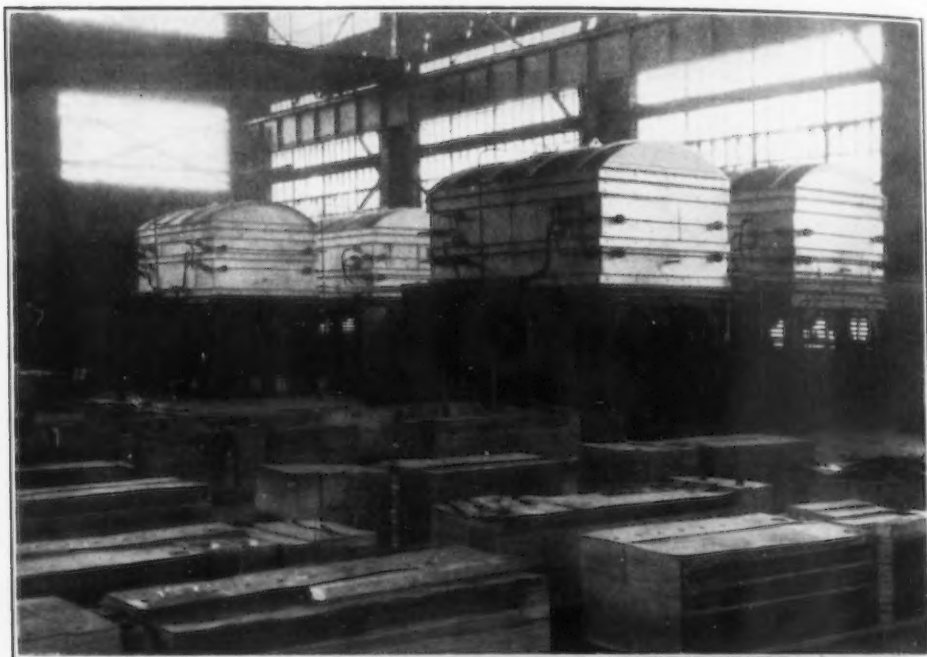


Fig. 12—Group of Elevator-type Furnaces for Annealing Sheet Steel for Electrical Machines.

fired furnaces, saving the cost of boxes, which is a large item, as well as the fuel and time required to heat them. Much of the space required to store them while cooling and some of the labor required to handle them and pack the material is also saved.

The boxes often weigh as much or more than the sheet steel itself, therefore twice the weight of steel must be heated, and the maintenance cost of the boxes is very high. It has been found that due to these factors, the cost of annealing with electricity is considerably less than the cost with oil.

These furnaces have been built in various sizes, from one ton to 10 tons capacity, and may thus be made in any size convenient for the manufacturing layout. In one instance a group of small furnaces is arranged in definite relation to the punch presses, so

that material travels from presses to furnaces on a fixed schedule.

Usually slow cooling is not essential, and the loaded car is removed from the furnace when soaking has been completed. A hood or cover is lowered over the charge to protect it from the air, and another charge is put into the furnace while it is still hot. This method of operation gives a large output per furnace and per unit of floor space, two or more charges per day being the usual schedule, and its advantages over the box method will be readily appreciated. The power consumed is about 200 kilowatt hours per ton depending on the size of furnace, and heating cycle.

A careful record was kept in 1924 on an electric furnace and a car-type oil-fired furnace to determine the relative cost and quality of anneal as a basis upon which to reach a decision regarding new facilities about to be installed. Both furnaces were practically new and of the same capacity, $3\frac{1}{2}$ tons to the load. The electric furnace used a steel plate upon which the sheets were loaded, and the oil furnace used one long pot to contain the sheets.

The plates cost \$18.00 each and are good for 30 anneals, the pots cost \$400.00 each and are good for 50 anneals. With $3\frac{1}{2}$ ton loads this makes the cost of plates 0.86 cents per 100 pounds and the cost of boxes 11.4 cents per 100 pounds.

No difference in quality was apparent from examination and none was found by magnetic tests. No difference in labor cost was claimed in this comparison, although some saving was expected in the contemplated installation.

The cost per 100 pounds annealed was found to be:

	Electric Furnace	Oil Furnace
Fuel	10.8 Kilowatt hours=13.5c	2.89 gallons = 16.5c
Bases or Pots	0.86	11.4
	<hr/> 14.36	<hr/> 27.9

The items of labor, overhead, maintenance, interest and depreciation, required to give the true cost cannot be published, but the above figures give the essential facts.

Three new furnaces, each of $3\frac{1}{2}$ -ton capacity, were contemplated, each to turn out 12 anneals per week, or 6300 tons annually. The estimated cost of three electric furnaces was approximately \$25,000.00 and the cost of operation \$23,000.00 per year less than with oil-fired furnaces.

It is sometimes asked why these furnaces will anneal steel without scale, when the atmosphere in the usual electric furnace is normal air.

The reason is that the steel contains considerable quantities of gases, which are liberated during the annealing process, so that the resulting furnace atmosphere is in fact reducing.

The following analyses of gas samples taken during a typical run, show the effect of gas liberation on the composition of the furnace atmosphere. The furnace was charged while hot.

Composition of Atmosphere in Furnace for Annealing Sheet

	Soon after Starting	At end of 6 Hours	At end of 10 Hours
	Per cent	Per cent	Per cent
Carbon dioxide	6.2	8.7	8.0
Oxygen	0.15	0.1	0.0
Carbon monoxide	24.5	14.4	13.75
Methane	8.0	0.0	0.0
Hydrogen	39.1	8.0	5.7
Nitrogen	22.05	68.8	72.55

It will be noted that the oxygen disappears almost immediately. The results from these furnaces is an outstanding example of the savings that electric heating will permit in some cases. Manufacturers of electrical machines have found these furnaces well suited to their requirements, and thousands of tons are annealed in them annually. One company has 25 of these furnaces of various sizes in operation. A list of installations follows.

Plant No.	No. of Furnaces	Used for
1	1	Electrical sheets
2	1	Electrical sheets
3	1	Electrical sheets
4	1	Electrical sheets
5	1	Steel Castings
6	1	Disk Wheels
7	1	Gear blanks
8	1	Steel Castings
9	25	Electrical Sheets
10	1	Electrical Sheets
11	1	Steel Castings

NEW DEVELOPMENTS

The progress in design of furnaces for heat treating has been supplemented by furnaces for other uses. Electric forging furnaces have already been mentioned. The method of heating for

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forging has an important effect on the quality of the finished parts, and it is perhaps the least carefully done of any preceding or subsequent operation. The opportunities for improvement in these operations are well worth the attention of able engineers, and will probably receive it. Although time and effort will be required to develop the electric furnace into forms and sizes required for wide application in the forging field, there is no doubt of its intrinsic value for the purpose, or of a demand for it.

It is well known that the efficiency of electric furnaces at high temperatures is relatively much better than for combustion furnaces; this being characteristic of the types. The physical hardship of working near forging furnaces is well known, and this hardship is due largely to heat that cannot be used effectively.

In the average small furnace, 9 to 10 gallons of oil are used per 100 pounds of stock forged. This will cost say 55 cents. Electric furnaces will use about 25 kilowatt hours per 100 pounds which at $1\frac{1}{4}$ cents per kilowatt hour will cost 31 cents. It is quite obvious that the cost of heat will be less with electric furnaces in the average case, and the advantages of greater comfort and higher efficiency of workmen, choice of location, saving in burnt stock, etc., are secured in addition.

The maintenance cost of these furnaces has yet to be determined, and it may prove to be equal to or more than for combustion furnaces, but it will be agreed that considerable latitude could be allowed on this item and yet show a gain in overall economy. Undoubtedly there are interesting developments to be made in this field.

Electric furnaces with atmospheres of protecting gas have recently been developed for copper-brazing steel parts together, making possible the assembly of complicated structures from simple parts by a strong alloy weld.

Atmospheres containing a substantial proportion of reducing gas such as hydrogen are essential, as its reducing action on oxides at high temperatures thoroughly cleans all surfaces, thereby performing the functions of a flux, as well as excluding air from the heating chamber.

Copper wire or chips are placed adjacent to the joints to be brazed, and the assembly heated to a temperature somewhat above the melting point of copper. The capillary action of the fluid

copper causes it to spread over the surfaces and to be drawn into the minutest joints between the parts.

Furthermore, the limited but definite solubility of iron in copper at these temperatures, causes an alloyed union or weld between the parts which is exceedingly strong and intimate. Relatively large surfaces can be effectively joined by this method, and

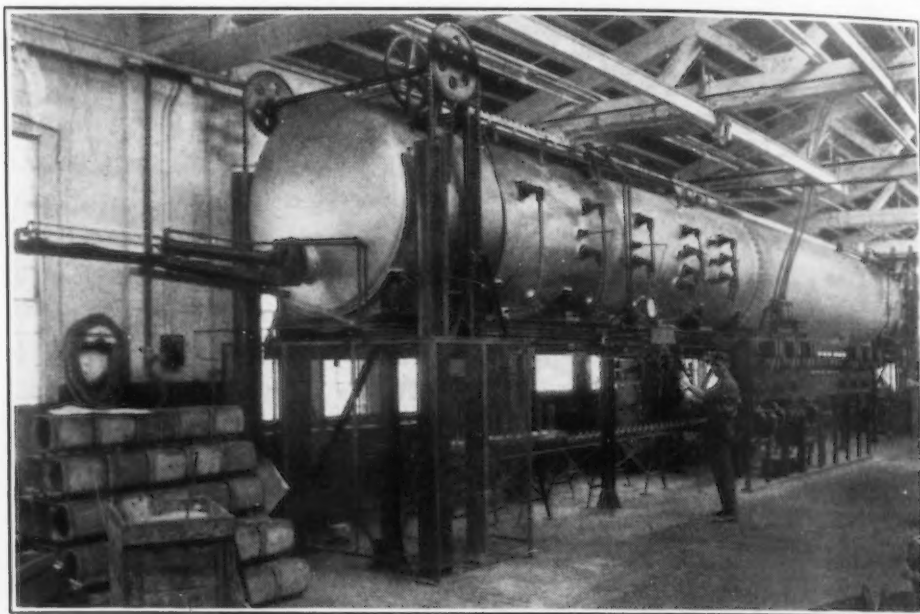


Fig. 13—Pusher-type Continuous Copper Brazing Furnace.

in ordinary practice dozens of joints are made in complicated assemblies at one operation. The work must be cooled as well as heated in the atmosphere of protective gas in order to prevent sealing, and this involves special types of furnaces if production requirements are to be met.

An intermittent type of furnace, adapted for large and small parts of various sizes and shapes, has been developed, and also continuous furnaces, adapted to a large output of a standardized product. One of these continuous furnaces is shown in Fig. 13.

The charging and discharging doors are on the under side of the shell and at opposite ends. The work is loaded on suitable trays which are pushed through on a roller track by a hydraulic cylinder. All controls are interlocked so that the operations must be carried out in the proper sequence.

Only a part of the furnace is equipped with heating units,

as may be noted by the terminals at the sides, the remainder being provided with a water jacket, so that the work is cooled well below oxidizing temperature before removal.

The technique of this method has also been fully developed during the past several years, and it is now employed extensively in important manufacturing operations by one company. It should be noted that electric furnaces have a unique advantage for processes of this kind, due to ability to control the atmosphere in them. Combustion furnaces are quite impracticable for this purpose. Furnaces of this type are also in use for bright annealing of certain nonferrous metals to which they are adapted.

Continuous furnaces have been suggested for bright annealing of sheets in sheet and tin plate mills. The possibilities of savings in the cost of boxes, pickling, labor of separating sheets which become stuck together, torn sheets, etc., are very attractive. The process outlined is one of the outstanding furnace developments of recent years, and the future may see many interesting applications of it.

Atmospheres of protective gas are used in some of the elevator-type furnaces previously described, for bulk annealing of sheet steel and lamination punchings. The atmosphere has a beneficial metallurgical effect on steels to be used for this purpose.

It is quite apparent that the day of scientific industrial furnace engineering has arrived, and that in the future, furnaces will be selected more and more for their application value, which visualizes them in their correct relation to other agencies of production. Preconceived ideas regarding the practicability of one kind of furnace or fuel to the exclusion of others, must give way to more careful analysis and appraisal.

The fields of usefulness for oil, gas, and electricity, will vary with the conditions to be met and with the locality. In the proper application of furnaces each will be used where it will enable the maximum overall economy to be attained.

There is no doubt that the development of electric heating has been a valuable contribution to the manufacturing industries, as an aid to improving quality, reducing cost, in providing better working conditions and enabling output per man to be increased. This art is relatively new, and appears to have vast possibilities for the future.



In preparing this paper an attempt has been made to show the present status of electric furnaces, the extent of their use for heat treating, some specific applications, and some new developments.

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In preparing this paper an attempt has been made to show the present status of electric furnaces, the extent of their use for heat treating, some specific applications, and some new developments.

ACKNOWLEDGMENTS

Acknowledgment is made of assistance from: George J. Hagan Co., Holcroft & Co., Wm. Swindell & Bros., The Electric Furnace Co. of America, W. S. Rockwell Co., for data and photographs which they have supplied. Also thanks are due to the managers of plants where the furnaces are installed for data which they have supplied and for opportunity to observe the furnaces in operation.

DISCUSSION

CHAIRMAN W. TRINKS: What Mr. Otis has said certainly is of great interest. I would like to ask about one little subject, namely, the temperature control. If I am not very much mistaken, the American Gas Furnace Company at Elizabeth had a temperature control for their furnaces, the patents of which ran out something like ten years ago, so I believe they were the originators of automatic temperature controls.

Also, in speaking of electric furnaces we should not forget to give credit to the mechanical engineer who has in 25 years reduced the coal consumption from three pounds per kilowatt hour to less than one pound per kilowatt hour, and he is still going strong, making it possible, probably, that in the future electric furnaces will compete even better than they are competing now.

It is an old saying that whenever you talk about the merits of the various types of furnaces, you can always produce a dog fight on short notice, and since there is no written discussion, I open the paper to discussion from the floor. Would any of the gentlemen like to discuss the paper?

W. C. SEARLE: Mr. Chairman, I wanted to bring out a point that Mr. Otis intimated but perhaps did not enlarge on very much. That is, in the use of a box-type electric furnace for intermittent work in a small plant you

have the advantage of time clock control on your furnace. A man running a furnace during the daytime does not have to wait in the morning for it to heat up, he can set his time clock and it will turn the furnace on at five o'clock or six, or any time desired, so his furnace is ready for use when he comes in. Also, your carburizing pots can be loaded during the day, put in the furnace, the furnace will carry the heat for the required number of hours and shut off, so that his pots will be ready to pull out in the daytime.

Also, I want to ask Mr. Otis what the boxes were made of that he shows for bar annealing. They looked like boiler plate. If they were, what is the life?

I would also like to ask him what material the floors of his box-type furnaces are being made of and their probable life.

MR. WATSON: (Toronto) I would like to ask for some information, and I presume others as well, in regard to the annealing furnace that Mr. Otis mentioned as being cheaper to operate with electricity than with oil. In order to bring that home to us in our own town, I would like to ask him what the rate was at which oil was purchased per gallon and at what rate electricity was purchased per kilowatt.

A. N. OTIS: Mr. Chairman, first, in regard to the mechanical engineer having increased the efficiency of boilers, we should also remember that the electrical engineer has increased the efficiency of generating equipment, which has quite as important an effect on the cost of electricity as the boiler. Also, the fact that the larger use of electricity by industry for all purposes, the development of water power, and the liberal return allowed by public service commissions on the capital invested has enabled the public utilities to attract sufficient capital to do their part toward upbuilding the service. Regarding Mr. Searle's point as to the use of time clocks, this is a very important advantage of electric furnaces. It was not overlooked, but there are so many points that could be brought out in a paper of this kind that it could be extended almost indefinitely.

Regarding the boxes for annealing the tool steel bars, they are usually made of steel plate. The Ludlum Steel Co., at Watervliet, have some of their "Delhi" metal boxes which have been used for three years in this work. I have looked those over very carefully and there is no apparent warping and no apparent deterioration. It would seem that those boxes are good for many more years of service. However, that is the only installation that I know of where alloy boxes are being used.

The material used for the floor and hearth plates in electric furnaces is the nickel-chrome-iron alloy. It goes under a number of trade names and I could not answer that specifically because the electric furnace companies use various materials.

Regarding Mr. Watson's question as to the rates for oil and electricity, I would say that the figures as given in the paper implied the cost of electricity was $1\frac{1}{4}$ cents per kilowatt hour and the cost of oil $5\frac{3}{4}$ cents per gallon.

HIGH CHROMIUM STEELS

BY OWEN K. PARMITER

Abstract

A paper discussing in general the composition, heat treatment and properties of high chromium steels, including the various low carbon, stainless steel types and the several high carbon-chromium die types. Special consideration is given to the more recent development of super stainless steel. The effect of various chemicals and other corrosive substances upon stainless steel is given in detail.

SINCE the beginning of the present century there has been an increasing tendency toward the development and application of alloy tool steels. The process of evolution, covering a period of less than thirty years, has produced two outstanding classes of steel—one, a high tungsten group, of which modern high speed is representative, and the other, a high chromium group, which includes numerous varieties of stainless steel and tool steel. The value of tungsten in tool steel has been recognized for some time, but only in very recent years has the worth of the more common alloy, chromium, been fully realized and appreciated.

IMPORTANCE OF CHROMIUM

Of all the elements utilized at the present time for alloying purposes in tool steel, chromium is possibly the most valuable and interesting on account of the diversified properties made possible by combining fixed amounts of it with varying proportions of carbon and other alloying elements. The knowledge of the influence which chromium has upon retarding the corrosion of iron and steel has been known, though not clearly understood, for many years. Recently, the effect of the associated carbon content has been carefully investigated. The outcome has been not only the production of the present series of stainless steels, in which the carbon contents are comparatively low, but also the development

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of steels in which the amount of carbon present is carried to the opposite extreme and is relatively high. These latter steels utilize the unique hardening effect of carbon and chromium when combined under proper conditions and can be made intensely hard and unusually resistant to wear.

Enormous quantities of ferrochromium are being used by the steel industry at the present time in the manufacture of chromium steels. The field of usefulness of these steels is fast reaching vast proportions as the users become better acquainted with their possibilities. While not always intentional, it is a fact that working details are seldom available when new steels are first introduced. It is, therefore, the purpose of this paper to discuss in a general way the composition, properties and applications of some of the more recent alloy steels which chromium has made possible.

STAINLESS STEEL

The most outstanding event in the metallurgical world during the period following the World War has been the utilization on a commercial basis of the non-corrodible properties of a steel containing chromium in excess of 12.00 per cent in combination with a low carbon content. On account of the wide application of ferrous metals to our present day industries, the problem of corrosion is of the greatest economic importance. As a result of the urgent demand for a steel with sufficient permanence to resist moisture and various atmospheric conditions, several types of stainless steel have been developed. The physical properties of these several types are such that almost any required degree of hardness and strength can be obtained, as well as the various combinations of toughness and elasticity. They are sufficiently resistant to such a wide range of corroding media as to be of inestimable value for engineering purposes.

Aside from the development and production of special types, the effect of progressive methods in producing sound and uniform material has been far-reaching.

MANUFACTURE

Stainless steel is essentially an electric furnace product on account of its high melting point and the unusual alloy content. Of all the steels known at the present time, it is possibly the most difficult to produce satisfactorily. Not only is the manufacturer

confronted by unusual and extremely narrow composition limitations, together with a peculiar combination of "air-hardening" and "red-hardness" properties, which makes its working extremely difficult, but experience has shown stainless steel to be the most susceptible to surface seams, internal segregates, and nonmetallic inclusions of any steel known to modern tool steel metallurgy.

It is an acknowledged fact that there can be considerable difference in regard to soundness, strength, hardness and resistivity in two stainless steels of identical chemical composition. Stainless steel is an ideal example of distinctive character in quality steel manufactured by tool steel methods. It is possibly the foremost of all modern steels in reflecting the personal care and knowledge of its maker. Discriminating users have for some time appreciated the importance of quality in this complex alloy steel and the extent to which the results obtained reflect the steel-making ability of its maker. Stainless steel is no longer an experiment but a superior steel with many special applications. After years of rigid testing, it has been accepted by the trade as a distinctive standard product.

TYPES

Stainless steel was originally intended for cutlery and for that purpose has proven a great success. However, the fact soon became apparent that the application of one type was incapable of satisfying the requirements of the many various purposes. For instance, a steel capable of greater hardness was demanded by manufacturers of surgical and dental instruments if stainless steel was to be applied to that industry. Cutlers were greatly interested in a better cutting edge and a more resilient blade. Builders of steam turbines required extremely high tensile properties and toughness in a steel which could be readily machined. Manufacturers of drop forgings were not satisfied unless a material could be obtained which was about as malleable as a soft low carbon steel and which did not possess air-hardening properties. As there was no chance whatever of producing such widely different properties in any one type of steel, the development of several new types was found necessary. A careful investigation has shown that about five distinct types are required to satisfy the demands of the trade. Accordingly, at the present time, stainless steel is being supplied in the following types:

Standard Cutlery Type (A)
 Modified Cutlery Type (B)
 Turbine Type (T)
 Malleable Type (M)
 Super Stainless (Nirosta Type)

It is the intention of the author to discuss each type separately, although, due to restriction of space, the discussion must necessarily be limited to the more important details.

CUTLERY TYPE—"A"

The typical composition of this type of stainless steel is carbon 0.35 per cent, chromium 13.50 per cent, and no nickel. The physical properties of this steel are shown in Table I. The mechanical

Table I
Tensile Properties of Stainless Steel (Cutlery Type)

0.35 per cent Carbon 13.00 per cent Chromium Oil-quenched at 1800 degrees Fahr. Tempered as indicated					
Tempered at Deg. Fahr.	Yield P. Lbs. Sq. In.	Ten. Str. Lbs. Sq. In.	Elong. % in 2"	Reduction Area %	Brinell Number
950	203,508	258,775	8.3	19.5	480
1000	195,508	250,275	6.6	15.9	460
1050	191,450	225,083	7.4	22.0	425
1100	170,558	197,183	10.2	32.7	375
1150	145,136	174,864	9.9	31.6	375
1200	131,670	159,284	11.7	37.9	335
1250	125,364	150,682	12.2	39.2	325
1300	121,155	146,798	12.4	40.5	315
1350	113,762	140,857	13.4	43.5	305
1400	103,900	130,975	14.4	45.8	285
1450	104,038	137,863	12.8	39.5	305
1500	114,138	159,975	12.4	34.0	340
Ann'd.	65,000	99,950	27.0	58.7	175

(Results are the average of numerous tests at temperatures indicated)

properties of the steel may be further modified by raising or lowering the quenching heat. The lower heats give better mechanical properties but at some sacrifice to hardness and stain resistance.

This type is the original stainless steel described by Brearley of Thos. Firth & Sons, Ltd., in his patent. It serves as an ideal material for many purposes. However, in order for it to show its maximum resistance to corrosion, it is necessary that it be hardened and then thoroughly ground and polished. This is often considered an objectionable feature, especially where grinding after hardening can be accomplished only with difficulty. It is sometimes advisable to resort to light pickling or sand blasting to overcome

difficulties of this nature. This type can be made reasonably hard but will not show the same intense hardness as will high carbon steel.

Being air-hardening, the steel must be annealed after forging if machine work is required. In all heating operations, it is necessary to preheat and then hold longer at the required heat than with ordinary steel. Forging is accomplished with more difficulty than with carbon tool steel. Frequent reheating is advisable. The following summary gives the temperature necessary for the proper working and treating of the steel:

<i>Operation</i>	<i>Temperature Range Degrees Fahr.</i>	<i>Resulting Hardness (Approximate) Brinell Number</i>
Forging	1700 to 2000	...
Softening	1400 to 1450	220
Annealing	1575 to 1625	165
Preheating	1450 to 1500	...
Hardening	1775 to 1850	550

Oil quenching for hardening is recommended for all of the various types of stainless steel. Very light or intricately shaped specimens may be cooled in an air blast but the resulting hardness will not be quite so high as if they had been quenched in light oil. In heating for hardening, stainless steel should be held about two or three times as long as ordinary steel to insure a uniform temperature. Wherever practicable, stainless steel should be given a thorough preheating at 1300 degrees Fahr. before being given the full hardening heat. This is especially applicable to heavy sections.

Aside from proper hardening, by far the most important process which influences stain resistance is that of grinding. Wet grinding is always preferred. The grinding must be deep and thorough. Every trace of forging scale and surface oxidation must be removed. Any remaining scale pits serve as seats for corrosion and an electrolytic action is set up which rapidly spreads over the surface of the material as rust.

In the past, it has been the belief of some that the surface stability of stainless steel was due entirely to the degree to which the surface had been polished. On the contrary, the stain and rust resisting properties are inherent in the steel, being the result of composition, combined with heat treatment. A smooth, highly finished surface is to be desired in order that no pits or spots shall exist where electrolytic action might start.

MODIFIED CUTLERY TYPE—"B"

The typical composition of this type of stainless steel is carbon 0.65 per cent, chromium 16.50 per cent, no nickel. This particular type was developed for the cutlery trade in an endeavor to incorporate some of the advantages of carbon steel into stainless material without sacrificing the stain resisting properties of the latter. In many respects, it works quite similarly to the original type except that a more intense hardness and a better cutting edge is possible. Being higher in both carbon and alloy content, the modified type works just a trifle harder and requires more frequent reheating and soaking, both for forging and hardening. It absorbs heat less readily than the other steel and should, therefore, be heated for a longer period of time to insure uniformity. No difficulty is experienced in rolling this type into various shapes, including light double bevels. Forging and heat treating may be accomplished by applying the following heats:

Operation	Temperature Range Degrees Fahr.	Resulting Hardness
		(Approximate) Brinell Number
Forging	1700 to 2000	...
Softening	1400 to 1450	230
Annealing	1625 to 1675	200
Preheating	1450 to 1500	...
Hardening	1875 to 1925	600

TURBINE TYPE—"T"

The typical composition of this third type of stainless steel is carbon 0.12 per cent and under, chromium 12.50 per cent, nickel under 0.50 per cent. The physical properties of this steel are shown in Table II.

Possibly the most rigid requirements to which any steel is subjected are those of blades in a steam turbine wheel. Not only must the maximum degree of strength and elasticity be obtained, but it is necessary that it be retained without sacrificing toughness and machining properties. This delicate balance between strength and hardness must be realized in a steel showing high corrosion resisting properties. Exact manufacturing methods in combination with the necessary composition and proper heat treatment have produced a steel of exceptionally good physical properties.

The United States Navy Department was among the first

Table II
Physical Properties of Stainless Steel (Turbine Type)

		0.11 per cent Carbon		12.50 per cent Chromium				
		Oil-quenched at 1800 degrees Fahr.		Tempered as indicated				
		Sections treated 1 3/4"x1"x7 1/2" long						
Tempered Deg. Fahr.	Brinell Hard- ness	True E. L. Lbs. Per Sq. In.	Proof Stress Lbs. Per Sq. In.	Yield Point Lbs. Per Sq. In.	Ultimate Strength Lbs. Per Sq. In.	Elong. %	Red. Of Area %	Izod Impact Foot Lbs.
None	401	60,000	72,000	177,000	200,500	18.5	56.5	50
		54,000	69,000	180,000	204,000	17.5	58.1	48
500	398	94,000	108,000	165,000	189,250	17.5	60.6	60
		94,000	108,000	171,000	196,500	17.5	59.4	60
700	393	117,000	126,000	165,000	187,000	17.5	62.6	60
		111,000	120,000	168,000	185,500	17.5	62.3	60
900	402	105,000	123,000	165,000	186,500	19.0	64.2	59
		120,000	132,000	171,000	196,250	20.0	60.3	40
950	402	105,000	123,000	165,000	190,000	22.0	63.0	38
		108,000	126,000	159,000	192,000	20.0	63.5	32
1000	392	99,000	117,000	168,000	197,750	20.5	62.1	34
		87,000	108,000	159,000	192,500	20.0	63.0	32
1050	371	87,000	102,000	156,000	178,500	20.0	63.8	26
		93,000	108,000	150,000	177,500	20.5	64.2	24
1100	313	81,000	96,000	144,000	156,500	20.0	65.6	36
		84,000	105,000	135,000	153,500	20.0	68.2	26
1150	260	84,000	90,000	105,000	122,500	22.5	69.7	60
		81,000	90,000	105,000	122,750	23.5	70.4	46
1200	252	75,000	84,000	102,000	120,000	22.5	70.1	99
		81,000	87,000	99,000	117,250	23.0	71.0	86
1250	230	72,000	75,000	87,000	108,500	25.0	71.9	106
		69,000	75,000	90,000	107,500	25.0	71.6	86
1300	220	60,000	69,000	84,000	103,750	25.0	69.9	108
		66,000	72,000	84,000	103,000	26.5	71.8	96
1350	211	61,000	69,000	81,000	102,000	27.0	71.6	111
		63,000	69,000	78,000	100,000	26.5	71.8	110
1400	202	60,000	66,000	78,000	98,000	26.0	72.9	117
		60,000	66,000	75,000	97,000	27.0	72.3	116
1450	196	51,000	57,000	69,000	93,000	30.0	74.1	118
		54,000	60,000	69,000	93,000	30.5	74.1	118
1500	297	33,000	42,000	117,000	144,250	18.5	55.2	32
		30,000	42,000	114,000	141,000	18.0	55.2	30
Annealed	152		39,000		81,000	36.0	75.8	118
1600			39,000		80,000	35.0	75.6	118

to realize the possibilities of this material. Their specification for physical properties for corrosion resisting steel for turbine parts is as follows:

Proof Stress	70,000 lbs. per sq. in. (minimum)
Tensile Strength	100,000 lbs. per sq. in. (minimum)
Elongation	20% in two inches (minimum)
Reduction of Area	60% (minimum)
Izod Impact	50 ft. lbs. (minimum)
Brinell Hardness	200 to 240
Rockwell Hardness	21 to 28 C.
Endurance	50,000 lbs. per sq. in. (minimum) as determined by rotating can- tilever at 10,000,000 cycles)

Engineers and those familiar with the difficulties presented in consistently obtaining maximum elastic limit in conjunction with a high Izod value will fully appreciate this steel.

The temperatures necessary for working and heat treating this material are as follows:

Operation	Temperature Range Degrees Fahr.	Resulting Hardness
		(Approximate) Brinell Number
Forging	1700 to 2000	...
Softening	1400 to 1450	200
Annealing	1550 to 1600	160
Preheating	1450 to 1500	...
Hardening	1775 to 1825	400 (de- pending upon size)

MALLEABLE TYPE—"M"

The typical composition of this type of stainless steels is carbon 0.08 per cent, chromium, over 16.00 per cent. As before mentioned, stainless steel in general is considered somewhat difficult to forge. Of course, it forges easier than high speed steel, but with considerably more difficulty than ordinary carbon steel. For this reason, since the first introduction of stainless steel, manufacturers of drop forged articles have requested a soft, malleable type which could be formed into intricate shapes with about the same ease as low carbon steel. Also, a material was preferred which showed little tendency to air harden following the forging operation.

All of these desirable features are incorporated in the "Malleable Type", which carries a low carbon content in connection with high chromium. It combines a high resistance to rust with excellent forging properties. As with other types, slow heating for forging is recommended. An initial heat of 2000 degrees Fahr. will give good results for general drop forge work. Slow cooling of the finished article is advisable. Suitable working heats are as follows:

Operation	Temperature Range Degrees Fahr.	Resulting Hardness
		(Approximate) Brinell Number
Forging	1600 to 2000	...
Annealing	1400 to 1450	140
Preheating	1400 to 1450	...
Hardening	1775 to 1825	300

SUPER STAINLESS (NIROSTA TYPE)

The super stainless type, while comparatively new in this country, has been extensively used for years in England and

Germany. A typical composition is carbon 0.15 per cent, chromium 18.00 per cent, nickel 8.00 per cent.

This particular type readily adapts itself to applications requiring stainless steel in strip and sheet form and in bars which are to be used for upset or cold-pressed articles as well as those which are machined. It possesses a high resistance against rupture and a remarkable ductility in the cold state, which make it capable of being pressed into a number of intricate shapes. It is ex-

Table III
Physical Properties and General Characteristics of Super Stainless Steel

	<i>Tensile Properties</i>		
	<i>Fully softened</i>	<i>Higher tensile condition</i>	
Yield Point	33,820 lbs. sq. in.	66,000 lbs. sq. in.	
Tensile Strength	108,860 lbs. sq. in.	119,620 lbs. sq. in.	
Elongation	62.8%	42.0%	
Reduction of Area	45.0%	35.0%	
Brinell Hardness	160 BN.	190 BN.	
Izod Impact	100 ft. lbs.	90 ft. lbs.	
	<i>SHEET</i>	<i>BAR</i>	<i>WIRE</i>
	(2"x1"x20 gage)	(2"x0.564")	
Yield Point	33,600 lbs. sq. in.	38,975 lbs. sq. in.	36,290 lbs. sq. in.
Tensile Strength	120,960 lbs. sq. in.	110,880 lbs. sq. in.	130,820 lbs. sq. in.
Elongation	65.0%	50.0%	65.0%
Reduction of Area .....	..	40.0%	..
Brinell Hardness .....	..	153 BN.	..
Izod Impact .....	..	105 ft. lbs.	..
Erichsen Test	13.8 m/m		

tremely tough and will withstand drastic deformation without bursting. The material shows its deep-drawing properties to the best advantage when in the dead soft annealed condition. Its resistance to the ordinary agencies of corrosion is exceedingly good.

It cannot be hardened to any appreciable extent by heat treatment, but reduction by working in the cold state has a tendency to both harden and refine it. By severe cold-working, a Brinell hardness in the vicinity of 400 can be produced. As indicated by its composition, the steel is of an austenitic nature and possesses the usual characteristics of that type. Annealing is accomplished by quickly cooling from a temperature of about 2100 degrees Fahr. In the very soft state, a Brinell hardness as low as 130 is possible.

General heat treating instructions are as follows:

Operation	Temperature Range Degrees Fahr.	Resulting Hardness
		(Approximate) Brinell Number
Forging	1750 to 2350	...
Softening	1600 to 1700	185
Complete softening	2000 to 2200 (cool rapidly)	140
Hardening.....	By cold working only— up to 400	
Tempering.....	Up to 750 improves ductility	

This steel is characteristically austenitic; the standard or normal condition, therefore, is that in which the structure associated with the austenitic state has been properly obtained, and it is in such a condition that the steel is most commonly supplied and employed. To put it into this condition, it is only necessary to heat it to a high temperature, 2000 to 2200 degrees Fahr., and rapidly cool.

It will be seen from the tests that the steel in this state combines, in a unique manner, softness equivalent to that of mild steel with a correspondingly low yield stress, and a very high ductility. The maximum stress in tension is comparatively high, being disproportionately so in relation to the Brinell hardness.

Torsion Tests

As regards the response to torsion in the fully softened condition, the following values are given:

Yield	21,280 lbs. sq. in. in shear stress
Shear Stress	100,800 lbs. sq. in. in shear stress
Degrees of Twist	450 on $\frac{5}{8}$ " round x $1\frac{3}{4}$ " long

Fatigue Strength

Fatigue tests are the essential means of judging the merit of the material intended for application in various machine parts and units where alternating stresses are to be encountered. The following determinations have been made on this material in the fully softened condition by means of the Wohler rotary bend test:¹

¹Quoted from Thos. Firth & Sons, Ltd., data.

Stress to \pm 38,080 lbs. sq. in.	14,000,000 revs. (unbroken)
Stress to \pm 40,320 lbs. sq. in.	640,000 revs. (broken)
Stress to \pm 42,560 lbs. sq. in.	292,000 revs. (broken)

From these figures it will be deduced that the fatigue limit of the material is between 38,000 and 39,000 pounds per square inch.

Effect of Cold Working

While this material cannot be hardened by thermal treatment, it can be substantially hardened by cold working, either by rolling, hammering or drawing. The material, owing to its great ductility, lends itself very readily to such processes.

The following results show the mechanical properties induced, by successively increased amounts of cold reduction in rolling, on strip:

	<i>Yield Point</i> (lbs. per sq. in.)	<i>Tensile Strength</i> (lbs. per sq. in.)	<i>Elongation</i> (% in 2")	<i>Brinell</i> <i>Hardness</i>
(a)	59,920	142,460	47.0	190
(b)	112,850	165,540	32.5	303
(c)	169,570	215,040	13.0	352

By carrying the cold working further, hardness values of over 400 Brinell may be obtained.

Effect of Heat Treatment After Cold Working

Tempering a cold-worked sample produces softening of the steel to a gradually increasing extent as the reheating temperature is raised. Reheating up to 750 degrees Fahr. improves the ductility without producing appreciable softening. Softening at higher temperatures is then progressive. Material similar to (c) above, tempered at about 750 degrees Fahr., makes a very good material for spring purposes. A yield point of 193,760 pounds per square inch, with a tensile strength of 212,800 pounds per square inch and an elongation of 14 per cent, has been obtained.

Coefficient of Thermal Expansion

<i>Range of Temperature</i> <i>Degrees Cent.</i>	<i>Mean coefficient of expansion</i> <i>per Degree Cent.</i>
20-100	0.0000170
20-200	0.0000177
20-300	0.0000182
20-400	0.0000186
20-500	0.0000190
20-600	0.0000195

Electrical Resistivity

At ordinary temperature, this type of stainless steel has an electrical resistance of 69 microhms per cubic centimeter.

Magnetic Properties

In the fully softened condition, the super stainless type is practically nonmagnetic, having a permeability of only 1.02 in this condition. Cold working renders it feebly magnetic.

Resistance to Scaling

Super stainless steel is extremely resistant to atmospheric oxidation at elevated temperatures. The summary shows the percentage gain in weight of $\frac{7}{8}$ -inch round by 4-inch long samples of this type, heated in an open end tube for 6 hours at a temperature of 1850 degrees Fahr.

<i>Material</i>	<i>Per Cent Gain in Weight</i>
Wrought Iron	0.75
Mild Steel 0.30 per cent Carbon	0.67
Mild Steel 0.45 per cent Carbon	0.70
1 per cent Carbon Steel	0.58
3 per cent Nickel Steel	0.65
3 per cent Nickel-Chromium Steel	0.66
Super Stainless	0.04

Strength at High Temperatures

Although this type should be compared with mild steel for its strength characteristics at and near ordinary temperatures, if the conditions imposed in working involve heating to high temperatures, from 950 degrees Fahr. upwards, the strength retained by it is far superior and for high temperature working it compares very favorably to special alloys made particularly for such work. The added property of "non-scaling" gives it a special adaptability for many purposes.

Specific Heat

The specific heat of steel does not vary greatly with composition. This particular steel shows a specific heat of 0.117.

Specific Gravity

	(<i>Super Stainless Nirosa Type</i>)	(<i>Cutlery Type "A"</i>)	(<i>Carbon Steels</i>)
Specific Gravity	7.925	7.760	7.880
Lbs. per cu. in.	0.2860	0.2800	0.2845
Lbs. per cu. ft.	494.0	483.7	491.2

Thermal Conductivity

In general, the thermal conductivity of metals varies inversely as the electrical resistance, and this steel conforms to this rule, as the following tabulation indicates:

<i>Material</i>	<i>Thermal Conductivity Calories per sq. cm. per degree Cent. per cm.</i>
Cutlery Type	0.050
Turbine Type	0.046
Super Stainless Type	0.033
Silver	1.000
Copper	0.920
Silver Plate	0.920
Ordinary Steel	0.060 to 0.1100
Pure Iron	0.146

Welding

Welding can be accomplished by all processes except that of the smith's forge. Electric welding provides the most desirable means, although very satisfactory welds can be produced by the oxyacetylene process.

Soldering and Brazing

This type of material can readily be joined either by soft or hard-soldering and by brazing. The usual precautions are necessary in each case.

Riveting

This operation presents no difficulty. On account of the great capacity of the steel for easy deformation, it can readily be riveted cold. In the larger sizes where hot-riveting is necessary, this process should be carried out at a temperature of 1850 to 2000 degrees Fahr.

De-Scaling or Pickling

The article or part to be treated should be immersed in an acid solution made up of equal volumes of water and commercial

hydrochloric acid, to which is added 5 per cent of the total volume of nitric acid and about $\frac{1}{2}$ per cent of a satisfactory restrainer. It is necessary after treatment in such a bath that the article be thoroughly washed in running water. An intermediate dip in an alkali bath is advantageous. This de-scaling operation produces a corrosion resisting finish, besides a very pleasing appearance.

Etching

No single acid will attack this steel in the cold state with sufficient rapidity to be effective as an etching reagent. A nitrohydrochloric solution of the following composition, used at room temperature, is recommended:

Hydrochloric Acid (1.16 Sp. Gr.).....	4 parts
Nitric Acid (1.42 Sp. Gr.)	3 parts
Water	4 parts

Machining

No particular difficulty is experienced in machining, providing certain reasonable precautions are taken and suitably shaped tools and proper cuts, speeds and feeds are adopted. Lubricant is to be generally recommended, and for certain operations is considered essential, especially in drilling. The machine tools with which this steel is to be handled must be both rigid and solid.

APPLICATIONS

A material with such a wide range of useful mechanical properties, coupled with the high degree of resistance to corrosion, naturally finds widespread application. Its use is specially indicated for various engineering purposes, among which may be mentioned the following:

Civil Engineering.—Gages, meters, surveying instruments, suspension ropes, rockers and rollers in bridge construction, apparatus in connection with sewage works, filtering beds, etc., rivets, bolts and nuts in inaccessible places where corrosion would be a serious factor, parts of lock gates, sluices and similar submerged fittings.

Mechanical Engineering.—Refrigerating machinery, compressed air apparatus, washing plants, feed regulators, steam traps,

superheated steam valves, pump rods and plungers, glands, links, screws, gear pumps, shafts, condenser tubes, measuring instruments.

Mining Engineering.—Power plant apparatus to include pipes, cables, conduits, ventilation, shaft sinking tools, screening plant, blasting machinery, underground haulage, boiler fittings, pump rods, pump cylinder liners, valve parts, impeller shafts, impeller blades, pins, links, levers, conveyor parts.

Railway Engineering.—Safety valve and stop valve parts, brake, piston and control rods, and levers working in contact with steam. Communicating wires for signals, levers, wheels and pulleys, pins for movable parts are parts especially suitable for the application of this steel.

Chemical Engineering.—It is especially valuable for outlet pipes for stills, condenser tubes and columns, pumps and fans used in the manufacture of nitric acid. It also finds a useful sphere in the construction of acid-mixing tanks, mixer-stirrers, pipe lines, pumps and nitrating pans in nitrating processes where a mixture of sulphuric and nitric acids is essential.

Automotive Engineering.—The unique corrosion resisting properties of this type of stainless steel, coupled with which it can be formed, soldered, brazed, welded, etc., renders it an excellent material for the bright fittings of the modern motor car or airplane. It serves admirably for pulleys and control appliances, propeller reinforcements, radiators, lamps, door handles, window lifts, dashboard fittings, ash trays and steering columns. Other general applications include hub caps, wheel spokes, wheel disks, mouldings, gear and brake levers, bumpers and a number of others.

The Domestic World.—In the culinary field, this material possesses distinct advantages over both silver and aluminum when applied to dishes and articles used in the preparation and serving of food. Plates, dishes, bread pans, frying pans, kettles, etc., show practically perfect condition after three years of actual use. Other articles made of this steel in daily use about the home include poker, fenders, bathroom fittings, stove fittings, door knobs, bells, hat and coat hooks, and ash trays.

Surgical Appliances.—The steel is being widely adopted in this important field for a great variety of purposes. From the hygienic point of view, it is proving invaluable.

Shop Furnishings.—Another field of usefulness is that of metallic fittings and utensils in food distributing shops and soda fountains. Containers, general fittings, rails, hooks, scales, weights, and many other items can be advantageously produced in this steel.

THE EFFECT OF VARIOUS CHEMICALS UPON STAINLESS STEEL

No discussion would be complete without some reference to the resistance which stainless steel offers to the many corrosive agents met in every day industrial and domestic life. The following summarizes the comparative effect of a number of reagents upon carbon steel, ordinary stainless steel and the most recent type of stainless steel described above as super stainless. As can be noted from this list, the stainless steels are unaffected by many of the corrosive materials which readily attack other steels. Even in the case of those substances to which stainless steel is not considered entirely resistant, the effect is much less severe and the superiority over ordinary steel is sufficient to be of immense value in many cases. A partial list of chemical agents and their effect on three different steels is as follows:

Reagent	Concentration in Per Cent	Carbon Steel	Cutlery Type Stainless Steel	Super Stainless Steel
			13.00 Chromium	18.00 Chromium 8.00 Nickel
Acetic Acid	100	Attacked	Unaffected	Unaffected
Acetic Acid	33	Attacked	Attacked	Unaffected
Acetic Acid	15 and 5	Attacked	Attacked	Unaffected
Acetic Acid Vapor	100 boiling	Attacked	Attacked	Attacked
Acetic Acid Vapor	33	Attacked	Attacked	Slightly at- tacked
Acetic Anhydride	100	Attacked	Attacked	Unaffected
Acetone	100	Attacked	Slight Corro- sion	Unaffected
Alum	10	Attacked	Attacked	Unaffected
Aluminum Sulphate	10, 5, 1	Attacked	Attacked	Unaffected
Ammonia	Sp. gr. 0.880	Unaffected	Unaffected	Unaffected
Ammonium Chloride	20, 10, 5, 1	Attacked	Slightly at- tacked	Unaffected
Ammonium Chloride (Boiling)	23, 5, 47	Attacked	Attacked	Very slightly attacked
Ammonium Nitrate	10	Attacked	Unaffected	Unaffected
Ammonium Sulphate	10	Attacked	Attacked	Unaffected
Ammonium Sulphate (sat.) + 5% Sulphuric Acid (50°C.)		Attacked	Attacked	Attacked
Apple		Attacked	Unaffected	Unaffected
Pear		Attacked	Unaffected	Unaffected
Benzol		Unaffected	Unaffected	Unaffected
Bleaching Powder	Aqueous suspen- sion	Attacked	Attacked	Slightly at- tacked
Boric Acid	5	Attacked	Unaffected	Unaffected
Bromine		Attacked	Attacked	Attacked
Bromine Water	3.3, 1.65 0.83	Attacked	Attacked	Attacked
Bromine Water	0.33, 0.165	Attacked	Attacked	Very slightly attacked
Calcium Chloride	10	Attacked	Slightly at- tacked	Unaffected

Reagent	Concentration in Per Cent	Carbon Steel	Cutlery Type Stainless Steel 13.00 Chromium	Super Stainless Steel 18.00 Chromium 8.00 Nickel
Carbolic Acid		Attacked	Attacked	Unaffected
Carbon Tetrachloride	As purchased	Attacked	Unaffected	Unaffected
Chlorine Gas	Wet and Dry	Attacked	Attacked	Unaffected
Chlorosulphonic Acid	Concentrated	Attacked	Attacked	Unaffected
Chlorosulphonic Acid	10	Attacked	Attacked	Unaffected
Chlorosulphonic Acid	0.5	Attacked	Attacked	Unaffected
Cider		Attacked	Attacked	Unaffected
Citric Acid	All concentra- tions	Attacked	Unaffected	Unaffected
Coffee	Conc. - aqueous extract	Attacked	Unaffected	Unaffected
Congo Copal (370° C.)		Attacked		Unaffected
Copal Varnish		Unaffected	Unaffected	Unaffected
Copper Carbonate	Saturated in 50 Ammonia	Attacked	Unaffected	Unaffected
Copper Chloride	5, 10	Attacked	Attacked	Attacked
Copper Sulphate	10	Attacked	Unaffected	Unaffected
Copper Sulphate (10%) + 2% Sulphuric Acid		Attacked	Unaffected	Unaffected
Developers:				
(a) Hydroquinone		Attacked	Unaffected	Unaffected
(b) Metol-Hydro- quinone		Attacked	Unaffected	Unaffected
(c) Pyro		Attacked	Very slightly attacked	Unaffected
Ether (Ethyl)	100	Unaffected	Unaffected	Unaffected
Ethyl Chloride	100	Attacked	Unaffected	Unaffected
Ferric Chloride	5, 10, 50	Attacked	Unaffected	Unaffected
Food Pastes		Attacked	Unaffected	Unaffected
Formaldehyde	40	Attacked	Unaffected	Unaffected
Formic Acid	100, 50, 25 and 5	Attacked	Unaffected	Unaffected
Formic Acid (Boiling)	50	Attacked	Attacked	Unaffected
Fixing Solution (Acid)	40 Hypo. 2.5 Pot. Met.	Attacked	Attacked	Unaffected
Horse-Radish Cream		Attacked	Slightly at- tacked	Unaffected
Hydrochloric Acid	All concentra- tions	Attacked	Attacked	Attacked
Hydrofluoric Acid		Attacked	Attacked	Attacked
Inks	I in 2 KI	Attacked	Unaffected	Unaffected
Iodine in Potassium Iodide Solution	Sat. and free I in 2 KI	Attacked	Attacked	Unaffected
Lactic Acid - Lemon	B. P.	Attacked	Attacked	Unaffected
Lime Juice		Attacked	Unaffected	Unaffected
Lime and Limestone		Attacked	Very slightly attacked	Practically unaffected
Lubricating Oils		Unaffected	Unaffected	Unaffected
Lysol	2 and conc.	Attacked	Unaffected	Unaffected
Magnesium Chloride	10	Attacked	Unaffected	Unaffected
Magnesium Sulphate	10	Attacked	Attacked	Unaffected
Milk	Fresh and sour	Attacked	Attacked	Unaffected
Mixed Acid (Nitric-Sul- phuric) (50° C.)	65 HNO ₃ 25 H ₂ SO ₄ 10 Water	Attacked	Attacked	Unaffected
Nitric Acid	Sp. gr. 1.42	Unaffected	Unaffected	Unaffected
Nitric Acid	Sp. gr. 1.20	Attacked	Unaffected	Unaffected
Nitric Acid	Up to 11	Attacked	Slightly at- tacked	Unaffected
Nitrous Acid	Sp. gr. 1.41	Attacked	Slight stain- ing	Unaffected
Nitrous Acid	5	Attacked	Slightly at- tacked	Unaffected
Oleic Acid	100	Attacked	Unaffected	Unaffected
Orange		Attacked	Attacked	Unaffected
Oxalic Acid	5	Attacked	Attacked	Unaffected
Paraffin		Unaffected	Attacked	Unaffected
Paregoric Compound		Attacked	Badly stained	Unaffected
Petrol		Unaffected	Unaffected	Unaffected
Phosphoric Acid	100	Attacked	Slightly at- tacked	Unaffected

Reagent	Concentration in Per Cent	Carbon Steel	Cutlery Type Stainless Steel 13.00 Chromium	Super Stainless Steel 18.00 Chromium 8.00 Nickel
Phosphoric Acid	75	Attacked	Attacked	Unaffected
Phosphoric Acid	50, 25 and 5	Attacked	Slightly at- tacked	Unaffected
Pickles		Attacked	Unaffected	Unaffected
Picric (Alcoholic)	Up to b. p.	Attacked	Unaffected	Unaffected
Potassium Nitrate	10	Attacked	Unaffected	Unaffected
Pyrogallie Acid	Up to b. p.	Attacked	Unaffected	Unaffected
Salt (Cerebos)	Moistened	Attacked	Attacked	Unaffected
Salt (Ordinary)	Moistened	Attacked	Attacked	Unaffected
Sauces		Attacked	Unaffected	Unaffected
Sea Water		Attacked	Slightly at- tacked	Unaffected
Sea Water (80° C.)		Attacked	Attacked	Unaffected
Sea Water (Agitated)		Attacked	Attacked	Unaffected
Sea Water (Intermittent Spray).		Attacked	Attacked	Very slightly attacked
Schaeff Acid (140° C.)	100	Attacked	Attacked	Attacked
Sodium Chloride	3, 5, 10	Attacked	Slightly at- tacked	Unaffected
Sodium Citrate	3.5		Unaffected	Unaffected
Sodium Hydroxide	33, 66	Unaffected	Unaffected	Unaffected
Sodium Sulphate	Saturated	Attacked	Unaffected	Unaffected
Sodium Sulphide	10	Attacked	Unaffected	Unaffected
Sodium Thiosulphate	30	Attacked	Unaffected	Unaffected
Sulphuric Acid	All concentra- tions	Attacked	Attacked	Attacked
Sulphurous Acid	B. p.	Attacked	Attacked	Unaffected
Tannic Acid	5	Attacked	Practically unaffected	Unaffected
Tartaric Acid (All tem- peratures up to boiling)	5, 10, 25, 50	Attacked	Attacked	Unaffected
Vinegar		Attacked	Unaffected	Unaffected
Water (Tapwater)	Running water	Attacked	Unaffected	Unaffected
Water (Tapwater)	15° C	Attacked	Unaffected	Unaffected
Zinc (450° C.)	L	Attacked	Attacked	Attacked
Zinc Chloride (Boiling)	(6°, 27.5°, 49°) (95° and 145°) (Tw.)		Very slightly attacked	Unaffected

(Room temperatures apply in all cases except where noted)

HIGH CHROMIUM TOOL STEEL

The discussion of high chromium steels so far has dealt mainly with the "stainless", or low carbon types, where resistance to corrosion is the primary object. Stainless steel, however, in all its various forms cannot be applied to the many cutting and forming operations for which tool steel is definitely adapted. It lacks the ideal hardened structure necessary for cutting metal. The carbides of chromium are present neither in sufficient amount nor in proper combination to permit of this. Apparently, most of the properties required in tool steel are sacrificed in an endeavor to satisfy resistance to corrosion.

Carbon and chromium form a complex series of carbides in the presence of iron. These carbides vary to a considerable degree

in composition, shape, size, hardness, brittleness and reaction to heat treatment. For some time it has been the object of numerous investigators to isolate certain of the more stable of these higher carbides which are intensely hard but brittle, and by the proper addition of certain alloys, modify their brittleness and other objectionable features, at the same time retaining and improving the desirable properties. Many compositions have been made in this endeavor; the most successful steels of this type have analyzed approximately as follows:

No. 1		No. 2		No. 3	
	Per Cent		Per Cent		Per Cent
Carbon	2.25	Carbon	1.40	Carbon	2.25
Silicon	0.25	Silicon	0.50	Silicon	0.20
Manganese	0.25	Manganese	0.25	Manganese	0.40
Chromium	12.50	Chromium	12.50	Chromium	12.50
Vanadium	0.25	Nickel	0.50	Nickel	1.00
		Cobalt	3.50		
		Molybdenum	0.80		

Several of these steels are quite satisfactory in many respects but lack certain desirable properties to make them ideal for special purposes.

Suitable Working Heats for These Steels

Operation	Temperature Range		
	No. 1	No. 2	No. 3
Forging	1650-2000° F.	1800-2000° F.	1700-2000° F.
Annealing	1550-1650° F.	1590-1610° F.	1550-1650° F.
Pre-heating	1200-1300° F.	1200-1250° F.	1200-1300° F.
Hardening in Oil	1700-1825° F.	1740-1750° F.	1675-1800° F.
Hardening in Air	.....	1880-1900° F.	.....
Tempering	300- 700° F.*	900-1150° F.*	400- 800° F.

*To suit purpose.

The most recent development of the high chromium die steels is a steel in which special consideration has been given to hardness and freedom from distortion. Its composition is somewhat different from the usual run of these steels, as shown by the following chemical composition range:

	Per Cent
Carbon	1.40- 1.70
Silicon	0.15- 0.30
Manganese	0.20- 0.40
Chromium	12.00-14.00
Molybdenum	0.50- 1.00
Vanadium	1.00- 1.50

This steel is a practical and well balanced one, possessing a number of valuable properties, among which are—

1. Intense hardness without brittleness.
2. Equal degree of hardness from air or oil quenching.
3. Extreme degree of resistance to abrasion.
4. Comparative ease of machining for a high alloy steel.
5. Minimum of dimensional changes and distortion.

The following summary gives the proper working and treating temperatures, and includes an indication of the hardness to be expected from the various operations:

Operation	Temperature Range Degrees Fahr.	Resulting Hardness (Approximate) Brinell Number
Forging	1700-1900	...
Annealing	1725-1760	200
Preheating	1200-1300	...
Hardening in air	1800-1875*	650
Hardening in oil	1780-1850*	650
Tempering	300-1000	650-600

*Within this temperature range, the smaller pieces should be hardened at the lower end of the range, and the larger pieces at the upper end.

In heating for hardening, it is necessary to preheat carefully in the vicinity of 1300 degrees Fahr. Practically the same degree of hardness results whether the material is air-cooled or oil-quenched. However, when air-hardening, it is advisable to pack in a container as a precaution against unnecessary scaling and decarburization.

APPLICATIONS

The intense hardness and remarkable resistance of this steel to abrasion make it valuable for many purposes, especially for dies. Remarkable records are being made with it by large users of all types of dies, including blanking, forming, trimming, extrusion and drawing, as well as punches, rolls and plug gages. It possesses considerable merit as a finishing steel and is particularly valuable in machining nonferrous metals, such as brass and bronze.

Radical improvements in any line of recognized value are rare occurrences. Tool steel is no exception to this rule. However, during the past few years, through extensive research and development work involving much time and expense, a great deal of

unusual progress has been accomplished in the improvement of alloy tool steels, especially those containing high percentages of chromium. These steels in the short time available have more than proven their worth. The user has greatly benefited through reduced costs and increased production. There are yet still greater possibilities to be developed. In the interest of the industry in general, it is to be hoped that those responsible for these improved steels will receive sufficient response and reward to encourage them toward renewed efforts in an endeavor to produce even better steel.

In conclusion, the author desires to acknowledge the generous co-operation of his employer, the Firth-Sterling Steel Company of McKeesport, Pa., and its associate, Thos. Firth & Sons, Ltd., of Sheffield, England, in granting permission to publish the data contained in this paper.

THE APPLICATION OF SCIENCE TO THE STEEL INDUSTRY—SECTION III

BY DR. W. H. HATFIELD

Abstract

The general subject of this section might be heating. Various forms of heating for particular purposes such as forging, annealing, normalizing, hardening and tempering, are discussed in some detail. The effect of forging on structure and properties is described. Thermal conductivity as influenced by various factors and the specific heats of iron and steel are covered.

MANIPULATION AND TREATMENT

Heating for Hot Work

THE problem of the time theoretically required for the heating of large masses is rendered exceedingly difficult, owing to the influence of such a great number of factors, many of which cannot easily be determined. A mass of steel placed in a furnace is heated (1) by radiation from the walls of the furnace and from the hot gases or flames, (2) by conduction, and (3) by convection, including actual licking of the surfaces of the mass by the flames or hot gases passing through the furnace chamber. Surface combustion may also take place as well as surface reactions, (such as oxidation), which also produces heat and helps in supplying the heat necessary to bring the mass up to the desired temperature. All the factors mentioned above affect the rate at which the surface of the mass absorbs heat. Even if this information were available, the time required for the heating operation would be difficult to ascertain, since further knowledge as to the thermal conductivity, specific heat and density is necessary for the complete solution of the problem. The factors are not constant, but vary with the temperature of the material, rendering an exact mathematical treatment of the problem impossible. To complicate matters

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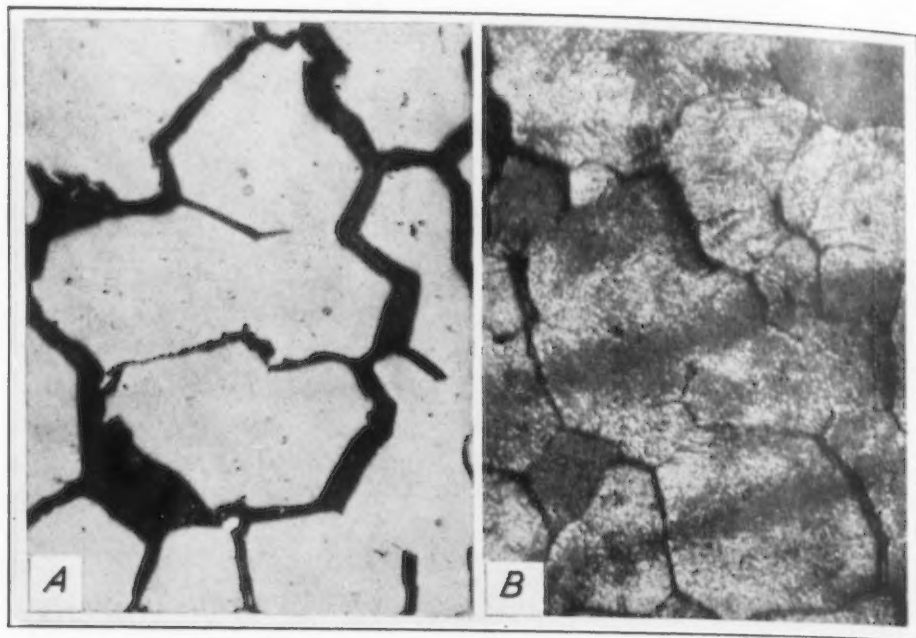


Fig. 15—Photomicrograph of Burnt Nickel-Chromium Steel. (a) Unetched. (b) Etched
× 25.

further, the heat of any transformation which might occur, materially affects the solution to some extent. Then again, the mass may be put into a cold furnace, or into one which is already raised to the desired temperature. These considerations are sufficient to indicate the complex nature of the problem.

However, in any effective steel works, practical usage and experience have resulted in tolerable procedure being adopted, but if such practice is critically examined, it will be found that convenience frequently dictates it. Ingots and blooms are not always given the discriminating time-temperature heating which theoretical considerations might suggest. Two considerations must be always before the operator. In the first place, the piece should be properly soaked through so that the optimum capacity for plastic deformation is attained; this will obviously be influenced by composition. In the second place, the time and the temperature gradient should be so regulated as not to produce overheating of the steel, or burning of the outer layers, otherwise oxide will penetrate fairly deeply along the grain boundaries as indicated in Fig. 15 (a) and (b) which show how nickel-chromium steel may be affected in this way. Excessive heating leads to the development of large grain size and sometimes, in such cases, to inter-

granular weaknesses which will frequently persist even after hardening and tempering. Only a very complete understanding of the time-temperature effect will enable this type of trouble to be

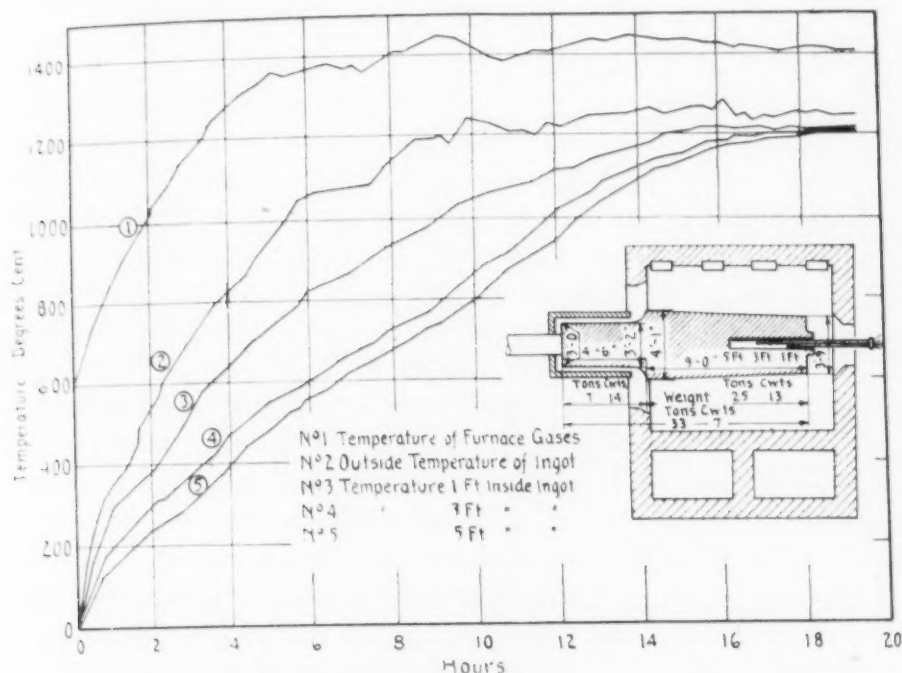


Fig. 16—Curves Showing the Rate of Heating of an Ingot at Various Points.

eliminated. Actual pyrometric studies, carried out on varying masses, are necessary to put this aspect of technique on a satisfactory basis.

A typical instance of such experiments may, perhaps, be usefully described, as carried out in the Firth works some time ago, viz., the heating up of a 30-ton ingot. The furnace used was coal-fired. A thermocouple was placed (1) in the furnace atmosphere, (2) on the surface of the ingot, (3) 12 inches inside, (4) 36 inches inside, (5) by means of an axial hole at the centre of the ingot. The temperatures were carefully recorded, and the data obtained disclosed in Fig. 16, enable sound deductions to be made concerning the necessary time-temperature treatment to obtain the uniform heating in such a mass, which is so essential. This experiment was intentionally based upon the using of a cold ingot, and it will be seen that the furnace had been reduced to a very low temperature before heating was commenced.

It is, of course, essential in handling very large ingots, to

Table IV
Forging Temperatures

Material	Suggested Maximum Forging Temperatures		Theoretical Burning Temperatures	
	Deg. Cent.	Deg. Fahr.	Deg. Cent.	Deg. Fahr.
1.5 per cent Carbon Steel	1050	1920	1140	2080
1.1 per cent Carbon Steel	1080	1980	1180	2140
0.9 per cent Carbon Steel	1120	2050	1220	2230
0.7 per cent Carbon Steel	1180	2140	1280	2340
0.5 per cent Carbon Steel	1250	2280	1350	2460
0.2 per cent Carbon Steel	1320	2410	1470	2680
0.1 per cent Carbon Steel	1350	2460	1490	2710
Silico-Manganese Spring Steel	1250	2280	1350	2460
3 per cent Nickel Steel	1250	2280	1370	2500
3 per cent Nickel-Chromium Steel	1250	2280	1370	2500
Air Hardening Ni-Cr Steel	1250	2280	1370	2500
5 per cent Nickel (Case hardening) Steel	1270	2320	1450	2640
Chromium-Vanadium Steel	1250	2280	1350	2460
High Speed Steel	1300	2370	1380	2520
Stainless Steel	1280	2340	1380	2520
Austenitic Chromium-Nickel Steel	1300	2370	1420	2590

transfer them hot to the forge furnace and subsequently to arrange the changes in temperature so as not to lead to the production of internal stresses with resultant possible internal damage to the forging. A comparison of modern practice, both as regards the technique of ingot manufacture, and as regards the knowledgeable way in which the ingot and bloom are taken care of during manipulation, at once brings home to one how much more reliable large forgings necessarily are which have been produced under modern conditions. With the avoidance of unduly high temperatures at the commencement of forging, which prevents the impairing of the intrinsic properties of the steel, and the care which is taken not to deform the steel when the heat has fallen too low, thus preventing internal rupture and local work hardening, some of the more serious troubles are eliminated. One very important point to be watched is the question of symmetrical and uniform heating; if this is not achieved, the result frequently obtained in the final forging is distortion of a mischievous and subtle kind.

When considering small forgings, exactly the same problems occur, but upon a smaller scale, and the author strongly holds that the utmost technical control is demanded and justified. The final heat treatment cannot always be relied upon to eradicate mishandling at this early stage. If steel is over-heated when heating for forging or rolling, the final mechanical properties of the steel are impaired. The liquidus and solidus of each type of steel should be determined, and the temperature should not be allowed to reach within 180 degrees Fahr. (82 degrees Cent.) of

1929

the solidus. Table IV gives an indication of the manner in which the permissible maximum heating temperature may vary for different steels.

Normalizing and Annealing

The terms "normalizing" and "annealing" are sometimes loosely applied to a variety of operations in a steel works. Steel in the forged or rolled condition has a nonuniform structure and is in a strained state, and in order to remove the stresses remaining from these operations, or, at any rate, to reduce them to a low value, it is necessary to reheat the material. This may be accomplished by either of the operations under discussion, but in addition to the necessity for reducing such stresses, it is necessary to modify the material by replacing the crystalline structure left by the hot work, with a refined one. The actual operation of normalizing consists in heating the steel above the A_{c3} point and allowing to cool in air free from draughts. Annealing is a much more thorough treatment, involving a knowledge of the behavior of the various steels under varied conditions. The original method of annealing was to heat the steel to a high temperature, maintain that temperature for a varying time, and cool very slowly. This is quite satisfactory for many steels, but in some of the alloy steels better results are obtained by heating to temperatures below the carbon change point, and cooling in air or in the furnace. In any case, it should be understood that the residual stresses are less as the speed of cooling is less. It may be of interest to include the British definition of these terms:

Normalizing. Normalizing means heating a steel (however previously treated) to a temperature exceeding its upper critical range, and allowing it to cool freely in the air. The maximum temperature shall be maintained for about 15 minutes, and shall not exceed the upper limit of the critical range by more than 90 degrees Fahr. (32 degrees Cent.).

Annealing. Annealing means reheating, followed by slow cooling. Its purposes may be—

- (a) To remove internal stresses or to induce softness, in which case the maximum temperature may be arbitrarily chosen.
- (b) To refine the crystalline structure in addition to the foregoing (a), in which case the temperature used must exceed the upper critical range as in normalizing.
- (c) In the case of tool steel, to modify the structure by balling up the carbides by using a temperature near to the carbon change point.

Hardening and Tempering

For many centuries, swords, knives, and the like, have been hardened and tempered, and the "finely-tempered" sword, an article in past ages much in demand, was produced long before pyrometric observations and the science of metallography had explained the fundamental principles of such processes. In considering the hardening and tempering of steel parts for airplane and automobile work, we are only following the example of the time-worn procedure of the old cutlers and armorers. Now, be it noted, that a novice would never, in the old days, have been permitted to harden and temper, only the highest skill and experience permitting the production of the desired results, and today the same remarks apply. There is quite enough scope in the art of hardening and tempering small and large parts, such as used in the various branches of engineering, to justify the growth of a class of operators with brains to understand and skill to execute the treatments required to obtain those excellent qualities which skillful hardening and tempering will induce. Bearing on this, it not infrequently happens that small parts are required in which one portion will have to be finely tempered and tough, whilst the other is quite hard, and even more difficult requirements can be met, providing the development of the necessary technique in the operator is insisted upon. In the whole range of steel metallurgy there is no direction where careful study and good technique can produce more valuable results.

The operation of hardening consists of quenching after raising the steel to temperatures above the critical points, at which it will exist as solid solution. In dealing with parts made of 0.3 to 0.4 per cent carbon and under, it is not sufficient to raise to a temperature at which the solid solution areas are formed from the pearlite, but the temperature must be attained at which the ferrite has also disappeared owing to its solution in the solid solution. The desirable temperature, therefore, for hardening, is that at which the steel is quenched as a completely homogeneous solid solution, and this temperature will depend upon the composition of the steel. If temperatures sufficiently high for this are not reached, we simply obtain residual ferrite, which reduces the effectiveness of the whole operation of hardening and tempering. Generally, temperatures from 1470 to 1560 degrees Fahr. (800

to 850 degrees Cent.) are quite sufficient for this operation, but the actual temperature depends upon the steel, and in this connection it is particularly important that the operator should appreciate the temperatures at which the changes take place in the given steel. It might be well here to caution against the use of too high quenching temperatures.

- (1) If the temperature is taken too high, and undue brittleness is introduced into the steel.
- (2) Quenching from higher temperatures naturally means greater internal stresses.
- (3) If too high temperatures are employed, the quenching medium, if of limited volume, becomes heated to a greater temperature during the quenching operation, and is, therefore, less effective in quenching the material, the speed at which the article passes through the critical zone being most important.

While discussing hardening, it might be well to point out that rapid heating should, for obvious reasons, be avoided. The question of hardening cracks bears very directly upon reliability, and it might here once more be emphasized that carelessness in hardening and tempering may vitiate the results of most excellent insight and care in design. It will also be fully appreciated that in the hardening operation, rapid changes in section, sharp corners, angles, etc., are a disadvantage just as in other items of process to which reference will be made.

With regard to the medium employed for hardening, that is determined by the character of the steel, and may either be water, oil or air. The mass of the forging to be cooled has a great effect upon the rate of cooling, which is, of course, the controlling factor. It is customary to talk of "quenching" large forgings, but the term is only a qualitative one when so used. The author, on one occasion, made quantitative temperature observations during the quenching of a 25-ton forging in 100 tons of oil. The rate of abstraction of heat from the forging which, at 1562 degrees Fahr. (850 degrees Cent.), was placed in the oil, having a temperature of 122 degrees Fahr. (50 degrees Cent.), was such that it required 30 minutes time before the oil had steadily risen to 169 degrees Fahr. (76 degrees Cent.) and the forging had only cooled to a mean temperature of 932 degrees Fahr. (500 degrees Cent.). To harden a forging of such mass, throughout, in such a medium, requires the introduction of elements sufficient to render the "breakdown of the solid solution" so sluggish as to prevent its

Table V
Oil-Quenched from 850 Degrees Cent.

	Tempered 932 deg. F. (500 deg. Cent.)			Tempered 1022 deg. F. (550 deg. Cent.)			Tempered 1112 deg. F. (600 deg. Cent.)			Tempered 1202 deg. F. (650 deg. Cent.)			
	1 hr. 1½"	1 hr. 2"	2½ hrs. 4"	1 hr. 1½"	1 hr. 2"	2½ hrs. 4"	1 hr. 1½"	1 hr. 2"	1 hr. 1½"	1 hr. 2"	1 hr. 1½"	1 hr. 2"	2½ hrs. 4"
<i>Tensile.</i>													
Elastic limit, lbs./sq. in.	114,700	80,300	67,000	97,000	55,000	67,000	82,900	70,500	58,200	52,200	62,500	66,100	60,500
Yield point, lbs./sq. in.	144,900	114,900	81,500	117,800	103,800	81,100	100,800	95,600	76,500	62,100	88,700	82,400	68,300
Max. stress, lbs./sq. in.	152,500	128,300	101,000	129,500	120,600	99,200	115,400	112,600	96,800	88,200	107,500	103,300	90,700
Elongation, per cent	15.0	20.0	23.0	21.0	21.0	23.0	24.0	24.0	25.0	27.0	26.0	26.5	26.0
Red. of area, per cent	49.7	57.5	61.5	63.6	61.5	61.5	66.8	65.7	64.75	69.25	68.8	67.8	66.8
<i>Torsion.</i>													
Shear Stress at Elas. Limit, lbs./sq. in.	92,500	77,600	51,700	70,100		47,000	61,800	59,200	47,500		45,900	49,200	45,900
App. Max. Shear Stress, lbs./sq. in.	134,600	117,200	98,600	112,700		96,366	101,200	103,400	94,300		99,200	95,900	92,800
Prob. Act. Max. Shear Stress, lbs./sq. in.*	101,000	88,100	73,900	84,400		72,100	75,900	77,600	70,800		74,600	72,000	69,200
Degrees twist	306	388	630	552		712	850	562	700		662	806	738
Izod Impact	30, 31, 29.	25, 25, 24.	39, 35, 37.	52, 51, 54.	43	35, 33, 33.	62, 67, 59.	59, 58, 57.	55, 53, 53.		100, 102, 101.	76, 74, 74.	76, 78, 60.
ft. lbs.													
Stanton Blows	12, 535	4, 966	1, 809	6, 620	3, 490	2, 176	6, 770	3, 023	1, 473		3, 110	2, 605	1, 716
Arnold	228	228	210	232	248	246	236	244	226		252	278	246
reversals	164	236	226	254	260	228	230	266	220		258	285	246
Brinell Numbers	321	311	212	269	255	207	241	241	197		217	217	179
Carbon	0.29%												
Manganese		0.33%											
Silicon			0.08%										
Sulphur			0.015%										
Phosphorus			0.011%										
Nickel													
Chromium													
	</												

*Based upon T. M. = $\frac{H}{12} d^3 \times$ shear stress.

occurrence under that rate of cooling. The use of water when quenching large masses, is permissible, but demands a very high standard in ingot production and in the subsequent operations. On the other hand, air-hardening is not admissible in very large masses.

The tempering operation, resulting in the degree of softening required, depends upon the particular temperatures to which the hardened part is submitted, the reheating causing the breaking down of the hardened state of the steel. There is not time in this short section to discuss the theory of the matter, and it will perhaps be well to give a typical example of what the effect of tempering at various temperatures for various times in various sections, may be upon a specific steel, see Table V.

The question should be discussed as to whether it is desirable to quench from the tempering temperatures. The author does not hesitate to say that such procedure tends to leave residual internal stresses of considerable magnitude, in the parts so quenched. Such is, however, the frequent procedure for the sake of the higher notched bar impact figures so obtained. Alloy steels are now available, notably those containing molybdenum, which do not demand such rapid cooling to obtain a good notched impact value. In any case, however, there are notable cases, particularly in turbine work, where internal stresses arising from such causes, are particularly to be avoided.

Whilst discussing the question of tempering, the author feels that he should emphasize the merit of two papers recently presented by H. A. Dickie⁸¹ and J. H. Whiteley⁸² respectively, which point to changes in the matrix of such steels within that range of temperature, of a sufficient order to require very careful consideration. This relates to the degree of solubility of the carbide.

Effects of Forging on Structure and Properties

The processes of hot working steel by forging and rolling have for their object, not only the production of shapes suitable for the purpose to which the steel is to be put, but also modifications in the condition and properties of the resulting product. Steel as cast, possesses certain inherent weaknesses. Such weaknesses are

⁸¹H. A. Dickie, *Journal, Iron and Steel Institute*, Vol. II, 1927, p. 223.

⁸²J. H. Whiteley, *Journal, Iron and Steel Institute*, Vol. II, 1927, p. 293.

a natural consequence of the manner of solidification. The process of crystallization of a large mass of metal is necessarily somewhat slow, and the resulting formation of relatively coarse crystals of varied composition and configuration, as previously discussed, leads naturally to variable mechanical and physical properties throughout the mass. In addition, a certain amount of looseness of structure, if not actual cavity, is necessarily left by reason of the varying contraction effects during the cooling of the mass, which exist at all stages from the beginning of solidification down to a uniform final temperature. Even in a correctly designed ingot, which is a casting in which all efforts have been concentrated on obtaining the best results as regards uniformity and solidity, it is shown (in the section dealing with Ingots, Section II) that the final result is far from ideal.

The forging of the steel has the effect of modifying the crystalline structure, by breaking up coarse crystals and massive segregated constituents, and also of knitting together and, in many cases, actually joining up by welding, loosely cohering or separated parts of the mass. It is well recognized that substantial improvements can be effected in castings by heat treatment alone. Mild steel castings are in use for many parts which have to withstand severe conditions of service and by suitable annealing after casting, mechanical properties are obtainable which are almost equal to those obtained in a good forging. A simple example of this is a locomotive wheel center casting. The annealing process causes a diffusion of the constituents—mainly the carbon in the steel—so that the original coarse and acicular formation of ferrite and pearlite is replaced by a relatively fine and redistributed ferrite and pearlite structure free from the obvious large planes of weakness previously present. There are, however, even in a carbon steel, certain features of structure which persist after heat treatment, and these are, in the main, based upon the arrangement and distribution of the impurities present in the steel. Slag and other nonmetallic inclusions appear to provide centers for the predisposition of the configuration of the new system of crystallization. By forging the steel, this configuration is distorted, and to some extent broken up, and the original tendency to a coarse formation is thereby considerably reduced. There is also the further effect that the coarse crystallization, which is probably

still present (as the gamma phase) after reheating for forging, is deformed to such an extent that recrystallization, while still in the high temperature zone, occurs on a finer scale, and by arranging for the finish forging to be at a satisfactory temperature, crystal growth has not time to take place. The final structure is, therefore, of a more refined order.

The presence and distribution of impurities in the steel do, however, assert their influence to some degree, on the final structure, and it is essentially this which leads to "grain" or fiber in the finished article. The well known "banded" structure in mild steel bars or plates, is an instance where some impurities—chiefly nonmetallic inclusions, but probably also affected by constituents in solution which have not been evenly diffused during the reheating operations—have located the first precipitation of ferrite during the recrystallization on cooling down through the recalescence zone of temperature. Such structures naturally run in the direction where greatest deformation from the original ingot has occurred. "Grain" or fiber is not, however, always associated with inclusions. In numerous examples where the steel has different properties longitudinally and transversely to the direction of forging, the inclusions are small and not numerous. The essential explanation, in such cases, of this, is to be found in two directions, (1) the steel may contain constituents which do not readily go into solution and diffuse when heated to the forging temperature. Such constituents will then behave, during forging, in a similar manner to nonmetallic impurities, so far as their orientation in the forging is concerned. (2) The steel may be of such a character that the "coring" effect produced during primary crystallization of the steel, which comprises variations in the composition of the original crystals from center to outside, still persists in spite of deformation of the crystals, and in spite of long exposure to forging temperatures. Such differences in composition within the small areas of the crystals, may be of an extremely small order, and yet, owing to the extremely slow rate of diffusion in the solid, of the compounds concerned, no approach to uniformity may be obtained. The distribution of the micro-heterogeneity will, therefore, be that of elongated shapes in the direction of forging. Such effects appear to occur in many alloy steels such as 3 per cent nickel-chromium steel. The distorted shapes of what

were apparently original dendrites in the "as cast" material, are frequently to be seen after macro-etching fairly large forgings.

The importance of "grain" is recognized practically, in many forgings, by the adoption of methods of carrying out the forging in such a way that the grain shall lie, in the finished article, in that direction most conducive to strength and capacity to resist the service stresses. The example of a crankshaft forged so as to obtain the flow round the webs and crank pins, may be quoted. The correct forging of die blocks, gear wheels, spring plate eyes, etc., demands consideration of this feature. The great value of the drop forging process arises largely from the adaptability of this process to ideal arrangement of the "fiber" in the resulting forging.

It should not be imagined, however, that forgings have strength only along the grain. Actual data as to the comparative strength along and across the grain,⁸³ show that it is exceptional for the difference in strength in the two directions, as judged by Wohler fatigue tests, to reach 17 per cent. The differences in elastic limit, yield strength and maximum stress in the two directions, are practically negligible. There are, however, differences in ductility of a measurable order, and notably in Izod impact values.

The best results of forging depend on the adoption of correct forging temperatures—the temperature should be high enough to give the steel the necessary plasticity, and not high enough to cause internal damage to the steel by overheating, which tends to cause intercrystalline weakness. The finish of the forging operation should be at the lowest temperature at which deformation can be reasonably produced, (unless the process is only a preliminary one). Adequate tools and power should be provided so that the work can proceed at a reasonable speed. The method of deformation should be such that the inside of the steel is worked as well as the outside. Many practical aspects of forging might be discussed, but space and time do not permit.

Reverting to the quantitative understanding of reheating problems, whether associated with reheating for hot working, hardening, normalizing, annealing, or tempering, it is necessary to have adequate data, particularly concerning thermal conductivity

⁸³Aitchison, *Journal, Iron and Steel Institute*, 1925.

and specific heat. A short review of knowledge extant upon these values, may be of interest and is, therefore, included.

The Thermal Conductivity of Steels. Influence of Composition and Temperature.

The accurate determination of the thermal conductivity of materials is rendered exceedingly difficult, chiefly on account of the lateral loss of heat by radiation. Many methods have been tried to take account of this loss, but considerable diversity exists in the results obtained. Before reviewing the effects of composition and temperature, therefore, it will be as well to note the varying values quoted for the thermal conductivity of pure iron.

Kohlrausch⁸⁴ gives 0.152 for wrought iron; Hobborn and Wien⁸⁵ give 0.156 for iron; Jaeger and Dieselhorst⁸⁶ give for pure iron, 0.161 at 18 degrees Cent. and 0.151 at 100 degrees Cent., and for wrought iron, 0.144 and 0.143 respectively; Hall⁸⁷ gives 0.1541; Hall,⁸⁸ correcting Angstrom's results, gives 0.1655; Simidu⁸⁹ extrapolating from the results of a series of carbon steels, obtained 0.1335, 0.1217 and 0.1284 for pure iron in the as-forged, annealed and quenched conditions respectively. Later,⁹⁰ he gives 0.134 for Swedish iron; Masumoto,⁹¹ using the same apparatus as Simidu, but a different series of steels, obtained by extrapolation, 0.1741. The observed value for a steel containing 0.1 per cent carbon and 0.38 per cent manganese, was 0.1447; Edser, in his book on "Heat", gives 0.166 at 0 degrees Cent. and 0.163 at 100 degrees Cent.; Benedicks, Backstrom and Sederholm⁹² deduce from observations on carbon steels, the value of 0.227 calories for pure iron. On a sample of iron containing 0.08 per cent carbon, 0.05 per cent silicon, 0.13 per cent manganese, the observed value was 0.187.

⁸⁴Kohlrausch, *Annales de Physique et Chimie*, No. 4, 1888.

⁸⁵Hobborn and Wien, *Zeitschrift des Vereins deutscher Ingenieur*, Vol. 40, p. 45.

⁸⁶Jaeger and Dieselhorst, *Abh. Phys. Tech. Reich*, Vol. III, 1900, p. 269.

⁸⁷Hall, *Physical Review* of the American Physical Society, May and June, 1900, p. 277.

⁸⁸Hall, loc. cit.

⁸⁹Simidu, Science Reports of Tohoku Imperial University, Vol. 6, No. 3, September, 1917.

⁹⁰Simidu, Science Reports of Tohoku Imperial University, Vol. 4, No. 3, November, 1917.

⁹¹Masumoto, Science Reports Tohoku Imperial University, Vol. 16, No. 4, May, 1927.

⁹²Benedicks, Backstrom and Sederholm, *Journal, Iron and Steel Institute*, August, 1926.

Ingersoll and co-workers⁹³ give 0.1428 for electrolytic iron melted in vacuo; Sedstrom,⁹⁴ on a pure electrolytic iron, gives 0.18.

It is difficult to account for the great variations in the values quoted above. In some cases (especially the earlier ones) the analysis of the material is doubtful. However, neglecting these and also those values deduced by extrapolation, we have a variation from 0.143 to 0.187. Some of the differences might be due to different temperatures of test or temperature ranges used for the test. Ingersoll used a method in which lagging merely was used to prevent radiation loss, and his results may be somewhat low. We are inclined to believe that the results of Benedicks and Sedstrom are somewhat too high, and on the whole we think the correct value for the thermal conductivity of pure iron at 20 degrees Cent. is between 0.16 and 0.17 c. g. s. units, and would take provisionally the value 0.165. This is very close to the value given in Edser's "Heat" and agrees with Hall's corrected values of Angstrom's results. While we think the Japanese method of measuring the conductivity is an excellent one and are inclined to place reliance on the individual determinations, we do not think that much importance should be placed on their extrapolated values for pure iron, since these were deduced by the method of least squares on so very few samples. The danger of this is revealed by the different results obtained by Simidu and Masumoto, who both used the same apparatus but a different series of steels. The value for pure iron deduced from both Simidu's and Masumoto's results would not be far removed from the value 0.165 we have decided upon.

Influence of Composition on Thermal Conductivity of Steels

Owing to the difficulty of measurement, the influence of composition has only been determined in a few cases. The influence of carbon has been determined by Simidu, Masumoto, Benedicks, Campbell and Dowd.⁹⁵ Campbell and Dowd did not make absolute determinations. Barrett, Brown and Hadfield⁹⁶ have also made relative determinations of a large number of steels, but the

⁹³Ingersoll, *Physical Review of the American Physical Society*, August, 1920, p. 126.

⁹⁴Sedstrom, *Inaug. Diss.*, Stockholm, 1924.

⁹⁵Campbell and Dowd, *Journal, Iron and Steel Institute*, Vol. II, 1917, p. 251.

⁹⁶Barrett, Brown and Hadfield, *Royal Dublin Society*, Vol. VIII, 2nd Series, 1904.

analyses given are incomplete so that allowances for other elements that might be present, cannot be made.

In dealing with influence of composition, it is perhaps best to consider the reciprocal of the conductivity, namely, the thermal resistivity rather than the conductivity itself, since it leads to more of a straight line relationship.

If the results of the foregoing observers are plotted, allowances being made for the silicon and manganese contents, (assuming that 1 per cent manganese increases the thermal resistivity by 2 units and that 1 per cent of silicon increases it by 4 units), Masumoto's results plot very well on a straight line up to about 3 per cent of carbon, when the line curves upwards somewhat. The initial slope of the line indicates that 1 per cent of carbon, when not in solution, increases the thermal resistivity by 2.5 units. Simidu's values are somewhat higher than Masumoto's and are irregular, but the general trend is a slope of the same magnitude. Campbell and Dowd's results agree fairly well with Masumoto's as regards the influence of carbon. Benedick's results are irregular. As regards the influence of carbon in quenched steels, the data available are not sufficient to form a definite opinion, but the indications are, that up to 0.9 per cent carbon, the rate of increase of resistivity with carbon content, is about 7 units per 1 per cent of carbon in the form of martensite.

The influence of manganese has been determined by Matsushita⁹⁷ and by Sedstrom.⁹⁸ The latter found that 1 atom per cent of manganese increased the thermal resistivity by 1.9 units, or about 1.95 units per 1 per cent of added manganese. Matsushita's steels all contained 0.2 per cent of carbon, the amount of other elements not being stated.

The direct determination of the effect of silicon appears to have been done only by Sedstrom, who found 1 atom per cent silicon increased the resistivity by 3.24 units, i.e., the 1 per cent silicon increased the resistivity by 6.48 units. Masumoto, from his results on carbon steels, gives 5.087 as the effect of 1 per cent silicon. Campbell and Dowd found that a steel containing 0.104 per cent carbon, 0.122 per cent manganese, and 3.649 per cent silicon, had 3.17 times the thermal resistivity of a relatively pure

⁹⁷Matsushita, Science Reports of Tohoku Imperial University, No. 8, 1919, p. 79.

⁹⁸Sedstrom, loc. cit.

iron when in the annealed condition, and 3.93 times when hardened. Assuming the value of 6.05 for pure iron, his standard would have a thermal resistivity of 6.08. This gives for the thermal resistivity of his silicon steel, values of 19.3 and 21.7 respectively. These figures, allowing for the carbon and manganese contents, indicate that 1 per cent silicon increases the resistivity between 3.5 and 4 units.

Nickel has been investigated by Ingersoll and his co-workers. The curve shows a sharp maximum at about 33 per cent nickel. The initial slope of the curve indicates that when in small amounts, 1 per cent nickel increases the resistivity by about 0.8 units. Sedstrom indicates that 1 per cent nickel increases the resistivity by 1.2 units.

Cobalt was studied by Honda⁹⁹ who found two maxima in the thermal resistivity concentration curve, occurring at about 9 and 91 per cent cobalt respectively, and a minimum at about 60 per cent cobalt corresponding to the formula FeCo_2 . The initial slope indicates that up to 5 per cent cobalt, 1 per cent of this element increases the thermal resistivity by 0.26 units.

The influence of tungsten has been studied by Honda and Matsushita, who investigated two series of tungsten steels containing 0.3 per cent and 0.6 per cent carbon respectively. The initial portions of the curves are irregular and one cannot deduce the influence of small amounts of this element.

Matsushita¹⁰⁰ investigated a series of chromium steels containing 0.6 per cent carbon. Some doubt must be placed on these results, however, since the difference between the results obtained on the quenched and annealed samples containing no chromium, are not consistent with the presence of 0.6 per cent carbon.

Influence of Temperature on the Thermal Conductivity of Steels

Hall,¹⁰¹ criticizing the various methods of measuring thermal conductivity, eulogizes Lorenz's method as particularly suited to studying the variation with temperature, and thinks that Lorenz's result is reliable. This gives the coefficient of variation with tem-

⁹⁹Kotaro Honda, Science Reports of Tohoku Imperial University, No. 8, 1919, p. 51.

¹⁰⁰Matsushita, Science Reports of Tohoku Imperial University, Vol. IX, No. 3, June, 1920.

¹⁰¹Hall, *Physical Review of the American Physical Society*, Vol. X, 1900, p. 277.

perature as -0.0002282 per degree Cent. Hall, using Berget's method, obtained on pure iron $K = 0.1541$ ($1 - 0.0003t$) and for cast iron, $K = 0.1512$ ($1 - 0.00075t$). Jaeger and Dieselhorst¹⁰² give $K = 0.161$ at 18 degrees Cent. for pure iron and 0.151 at 100 degrees Cent., the corresponding values for wrought iron being 0.144 and 0.143. Callendar, for a cast iron (2 per cent carbon, 3 per cent silicon, 1 per cent manganese) gives 0.114 at 54 degrees Cent. and 0.111 at 102 degrees Cent. Jaeger and Dieselhorst, for a 1 per cent carbon steel, give 0.108 at 18 degrees Cent. and 0.107 at 100 degrees Cent. Lees found a slight increase in the thermal conductivity of steel, from -180 to $+18$ degrees Cent. (from 0.113 to 0.115). Apart from these isolated attempts, the only real attempt to study the influence of temperature on the thermal conductivity of steels, is that by Honda and Simidu.¹⁰³ These authors measured the thermal conductivities of a series of carbon steels at temperatures up to 1650 degrees Fahr. (900 degrees Cent.). They found that the conductivity of a Swedish iron falls fairly rapidly with increase of temperature, from 0.134 at 30 degrees Cent. to 0.085 at 1145 degrees Fahr. (620 degrees Cent.). After passing the critical range, the conductivity remained fairly constant at 0.077.

The initial rate of fall (up to 100 degrees Cent.) indicates a coefficient of -0.0003 per degree Cent. in agreement with that of Lorenz. This coefficient is considerably reduced with increasing alloying content. With more than 0.44 per cent carbon, the thermal conductivity remains tolerably constant up to about 570 degrees Fahr. (300 degrees Cent.) when it begins to fall until the critical range is reached. Beyond the critical range, a slight rise of conductivity with temperature is indicated. It is clear that much more work is needed in this field.

Specific Heat of Steels as Affected by Temperature and Composition

For problems concerning the flow of heat, it is usual, in order to simplify the calculations, to assume a constant value of the specific heat over the whole range of temperatures concerned. It

¹⁰²Jaeger and Dieselhorst, loc. cit.

¹⁰³Kotaro Honda and Simidu, Science Reports of Tohoku Imperial University, Vol. VI, No. 4, November, 1917, p. 219.

will be seen, however, from the following review of work on the subject, that this constancy is far from being realized, even in the case of pure iron between 0 and 2730 degrees Fahr. (1500 degrees Cent.). Further, although the influence of added elements has been studied in a few cases at temperatures not far removed from normal, only in the case of carbon has the influence been studied up to temperatures in the neighborhood of 1590 degrees Fahr. (1200 degrees Cent.). From these results it is evident that it would be unwise to infer that the variations in specific heat, at ordinary temperatures, produced by the addition of a certain element, would be the same at elevated temperatures. However, it is as well to review the work which has been done in this direction.

Specific Heat of Pure Iron

Of the numerous attempts made to determine the specific heat of pure iron, fair agreement has been reached for the value of this constant in the range 0 to 100 degrees Cent. The following is a list of most of the determinations:—

Umino ¹⁰⁴	$S_0^{100} = 0.1102$
Oberhoffer and Grosse ¹⁰⁵	$S_0^{100} = 0.1107$
Oberhoffer ¹⁰⁶ , $S_0^{250} = 0.117$,	S_0^{100} (extrapolated) = 0.1105
Honda ¹⁰⁷	$S_{20}^{150} = 0.1126$
Harker ¹⁰⁸ , $S_0^{200} = 0.1175 =$	S_0^{100} (extrapolated) = 0.1117
Wust, Meuthen and Durrer ¹⁰⁹	$S_0^{100} = 0.1111$
Naccou ¹¹⁰	$S_0^{100} = 0.1117$
Bystrom [*]	$S_0^{100} = 0.1126$
Nichol [*]	$S_{15}^{100} = 0.1152$
Tomlinson [*]	$S_0^{100} = 0.1130$
Lorenz [*]	$S_0^{100} = 0.1107$

The more recent of these results are all not far removed from 0.111 units: as for the variation of specific heat with temperature,

¹⁰⁴Umino, Science Reports of Tohoku Imperial University, No. 5, 1926, p. 597, and No. 3, 1926, p. 332.

¹⁰⁵Oberhoffer and Grosse, *Stahl und Eisen*, Vol. 47, April 7, 1927, p. 576.

¹⁰⁶Oberhoffer, *Stahl und Eisen*, Vol. 27, 1907, p. 1764.

¹⁰⁷Kotaro Honda, *Japanese Journal of Physics*, Vol. 1, No. 7, 8, 1922, p. 71.

¹⁰⁸Harker, *Proceedings*, Physical Society of London, 19, 1905.

¹⁰⁹Wust, Meuthen and Durrer, *Stahl und Eisen*, Vol. 38, 1918, p. 177.

¹¹⁰Naccou, *Atti. R. A. de Torino*, Vol. 23, 1889, Beiblätter, Vol. XII, 1888, p. 326.

^{*}Bystrom, Nichol, Tomlinson and Lorenz taken from Physico Chemical Tables, Castell-Evans, Griffins, 1902.

1929

however, agreement is not so good. They all agree, however, that the specific heat increases with temperature, rising very rapidly just below the magnetic change point. The specific heat is maintained constant throughout the gamma region, at a value between 0.145 and 0.166 units. Some investigators report that the specific heat in the delta region returns to the value which it had in the alpha region above the magnetic change point.

Effect of Composition

As regards the influence of carbon, Honda¹¹¹ gives the mean specific heat between 20 and 150 degrees Cent. of a series of carbon steels, and his results plot fairly well on a straight line, which indicates that for this range of temperature, 1 per cent carbon in annealed steels, increases the specific heat by 0.0058 units. Umino¹¹² has also determined the specific heat of a series of carbon steels in the whole range up to 2280 degrees Fahr. (1250 degrees Cent.). His results, while slightly below those of Honda, indicate approximately the same influence of 1 per cent carbon (actually 0.0052 units). Brown¹¹³ has determined the specific heat of a number of steels. His specimens were all water-quenched from a cherry red heat and presumably, therefore, in some cases, were in the hardened condition. This may account for his values for the higher carbon content, being somewhat greater than those of Honda and Simidu. Umino showed that anomalous changes took place in the region of the allotropic changes. He also showed that the increase in specific heat with carbon content is not maintained at the higher temperatures, and that in the gamma region, high carbon content causes a considerable fall in the specific heat.

As regards the influence of manganese, from Brown's results it would appear that 1 per cent manganese in small amounts, increases the specific heat (0 to 100 degrees Cent.) by 0.0006 units.

As regards the influence of silicon, we have only Brown's results to guide us. He deduces that 1 per cent silicon in amounts up to 2 per cent increases the specific heat by 0.003 units: above this amount it has no effect. However, from both Honda's and Umino's results on carbon steels which contained varying amounts

¹¹¹Kotaro Honda, loc. cit.

¹¹²Umino, loc. cit.

¹¹³Brown, *Transactions, Royal Dublin Society*, Vol. IX, Series II, 1905-1909, p. 59.

of silicon in small amounts, it would appear that the influence of silicon up to 2 per cent is not so great as Brown indicates. Oberhoeffler and Grosse report that a transformer iron containing 4 per cent silicon, has lower specific heat in the range 0 to 100 degrees Cent. than pure iron, having a value of 0.1080 compared with 0.1107 for pure iron. They state further that in the range above the magnetic change point (there is no gamma range) the true specific heat is constant at 0.18475, compared with 0.165 in the case of pure iron in the alpha and delta ranges above the magnetic change point.

The influence of nickel on the specific heat of steels has been studied by Ingersoll and his co-workers¹¹⁴ and by Kawakami.¹¹⁵ Both investigators reveal a maximum in the specific heat at 35 per cent nickel corresponding with the composition of Invar. Kawakami reports a minimum at 85 per cent nickel where Ingersoll finds none. There are wide differences in the actual values of specific heat quoted by the two observers.

With regard to the influence of other elements, excepting that of Brown, no other work on the influence of elements other than those already mentioned appears to have been published. The following are Brown's conclusions:—1 per cent tungsten increases the specific heat of iron by 0.0028 units, when in amounts below 1 per cent. With 3.5 per cent tungsten, the specific heat falls to that of pure iron, and a further addition of 12 per cent of this element decreases the specific heat by 0.0093 units. 1 per cent aluminum has no influence on the specific heat of iron. Chromium, copper and cobalt have no effect on the specific heat of iron when large amounts of carbon are present.

¹¹⁴Ingersoll, *Physical Review of the American Physical Society*, August, 1920, p. 126.

¹¹⁵Kawakami, *Science Reports of Tohoku Imperial University*, Vol. XV, Series I, No. 2, May, 1926, p. 251.

(To be continued in June issue of TRANSACTIONS)

Educational Section

These Articles Have Been Selected Primarily For Their Educational
And Informational Character As Distinguished From
Reports Of Investigations And Research

THE CONSTITUTION OF STEEL AND CAST IRON SECTION II—PART VIII

By F. T. SISCO

Abstract

This installment, the eighth of the present series, describes the tempering of hardened steel. Preliminary to an explanation of the theory of tempering, the object and the various operations connected with this phase of heat treatment are discussed, as well as the various temperatures used and the proper time for holding at the tempering temperature. The discussion of the theory of tempering includes a description of the structural changes taking place in tempering and also the structural changes which occur when a high carbon steel is cooled at various rates followed by tempering. The effect of tempering upon the structure of a high carbon steel is illustrated by representative photomicrographs.

FROM the previous discussion that we have had concerning hardening it is plain that by regulating carefully the rate at which steel is cooled from above the transformation range to atmospheric temperature, we can obtain almost any structural condition that is desired and, naturally, can secure the physical properties characteristic of this structural condition. Thus if we heat a small piece of 1.00 per cent carbon steel to about 1400 degrees Fahr. and quench it in cold water a structure consisting principally of martensite will be formed. The quenched steel will have a high tensile strength, a

This is the eighteenth installment of this series of articles by F. T. Sisco. The several installments which have already appeared in TRANSACTIONS are as follows: June, July, August, September, November, 1926; January, February, April, June, August, October, 1927; February, April, June, November, 1928; January, March, 1929.

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high Brinell hardness number but at the same time will be very brittle, it will have little or no ductility.

Now if we quench the piece in oil, or permit it to cool in still air, or slowly with the furnace, different structural conditions will result, with their accompanying characteristic properties, conditions which depend primarily on the rate of cooling, that is, how fast the heat is extracted from the steel. Thus by regulating this variable we may have a structure which consists of martensite, troostite, sorbite, pearlite or mixtures of two or more of these constituents.

Theoretically it is easily possible by regulating the rate of cooling in quenching to obtain any hardness or strength that is desired. Practically, however, it is not easy. If we require a hardness of approximately 350 to 400 Brinell number we can obtain this hardness by quenching the piece in oil. But there is a disadvantage in this method of securing the desired physical properties, and that is the difficulty of having the desired properties uniform in all parts of the piece. It is quite obvious that if we quench a bar of tool steel three inches in diameter so that the hardness will be 350 Brinell number, the heat from the central portion of the bar will not be extracted as fast as the heat from the surface. The hardness near the surface may be 350 but at the center it will be much below this.

In order to assure ourselves of a uniform hardness throughout a section, the only positive method is to cool so that the hardness in all parts of the piece will be greater than is desired and follow this quenching operation by reheating to reduce the hardness to the desired point. This operation of reheating a quenched piece of steel to reduce the hardness is known as tempering, sometimes, especially by the practical heat treater, as drawing.

THE OBJECT OF TEMPERING

It is evident, then, that the first object of tempering is to reduce the hardness of a quenched piece of steel so it will be uniform throughout its cross section. But this is not the only advantage. Tempering relieves quenching strains. We saw in a previous discussion that rapid quenching results in a structural condition that is extremely unstable. Drastic hardening also produces internal strains in the metal. These strains arise from the physical con-

traction that the steel undergoes in quenching when the surface cools more rapidly than the center or when a thin section cools faster than a thick section. The internal stress set up in some steels is so high that it is no uncommon occurrence for a piece of hardened high carbon steel to go to pieces spontaneously—sometimes with almost explosive violence—within a few hours. Tempering relieves these strains.

Tempering, therefore, has two principal functions: to reduce the hardness and to relieve hardening strains. In reducing the hardness the ductility is increased. Tempering also induces a return, slight or pronounced as the case may be, of the very unstable martensite to the more stable troostite or the still more stable sorbite.

THE TEMPERING OPERATION

The tempering operation consists of heating a quenched steel to some temperature between atmospheric and A_{c1} , the lower critical point. Temperatures below 400 degrees Fahr. (200 degrees Cent.) do not reduce the hardness materially but they do decrease the brittleness and relieve hardening strains. Tempering between 400 and about 750 degrees Fahr. (200 and 400 degrees Cent.) results in reducing the hardness and strength and increasing the ductility still further. In this range there is an almost complete conversion of martensite to troostite. Tempering between 750 and 1100 degrees Fahr. (400 and 600 degrees Cent.) reduces the hardness and strength and increases the ductility still more. The structure has now been transformed to sorbite.

Let us view these changes briefly from the standpoint of stable equilibrium. When a high carbon steel is slowly and uniformly cooled to room temperature from some point above the lower critical point, A_{r1} , the normal structural change is from austenite, stable above A_{r1} to pearlite stable below this temperature. When cooling through the A_{r1} point is accelerated this normal change is inhibited and the steel is in metastable equilibrium at atmospheric temperature. The more rapidly the material is cooled through A_{r1} , the more drastic the quench, the more unstable will be the structural condition which results. It is evident that the most unstable condition possible is the retention of the austenite. This is rarely attained, consequently the most unstable condition frequently encountered is the structure known as martensite.

At atmospheric temperature the quenched steel is too rigid for the transformation to stable equilibrium to take place even though there is present a strong inherent tendency for it to do so. A very slight heating, however, produces some plasticity and a change occurs. The change is readily noticeable in quenched high carbon steel tempered at 300 degrees Fahr. (150 degrees Cent.) If the temperature of reheating is increased the material becomes still more plastic and there is a further change to a more stable structural condition. Thus in tempering carbon steels the change is from martensite, the most unstable, to troostite, more stable, and finally to sorbite the most stable structural condition at atmospheric temperature that results from reheating below the critical range. The higher the temperature to which the steel is heated the more readily and more completely the transformation to stable equilibrium takes place.

In addition to these structural changes taking place in tempering the strains introduced by drastic quenching are relieved. It is only necessary to heat to 300 to 400 degrees Fahr. to relieve these hardening strains, but the higher the tempering temperature the more rapidly they are removed.

TEMPERING TEMPERATURES

The effect of reheating a drastically quenched high carbon steel is first noted at a temperature of about 200 degrees Fahr. (100 degrees Cent.). Tools which must be very hard such as razors, some classes of drills, lathe tools and the like, are tempered between 200 and 400 degrees Fahr. Higher temperatures are used for such tools as taps, dies, reamers and the like. In the HANDBOOK⁴⁴ is listed the proper tempering temperature for the various classes of tools. The same authority recommends a temperature of 350 to 375 degrees Fahr. for removing hardening strains, a temperature of 400 to 500 degrees Fahr. to relieve strains and reduce brittleness and 500 degrees Fahr. as a toughening treatment.

Structural steels including both plain carbon and alloy grades are tempered at temperatures ranging from 400 to 1200 degrees Fahr. In this class, which does not include tools, high hardness is not so essential as a combination of hardness, strength, and ductility or toughness, consequently the temperature is usually deter-

⁴⁴American Society for Steel Treating, 1929 edition, pages 94-96.

mined by the use to which the steel is to be put. In most engineering steels, high strength, high resistance to impact and good ductility are all desirable. Since the tempering operation increases the ductility, but at the expense of the strength, the heat treatment of structural steels, especially in the automotive and aircraft industries is in the nature of a compromise in which the strength, toughness, resistance to shock and economy of machining are all taken into consideration.

In general, steel is held at the proper tempering temperature just long enough for the heat to penetrate completely through the section. It is customary for a few heat treaters, at least for some of the older ones, to judge the temperature by the color of the oxide films that form on the bright, scale-free surface of the steel. These temper colors range from a pale yellow appearing at 425 degrees Fahr., through straw, brown, purple, bright blue, to dark blue, at 600 degrees Fahr.

There is but little question that holding for a relatively long period at the tempering temperature increases the softness. It is well known that the same temper color will result from heating to two different temperatures for different lengths of times. Sauveur⁴⁵ gives the following example: "The same amount of tempering would result (a) from heating hardened steel to 550 degrees Fahr. when its color is bright blue, followed by immediate cooling, and (b) from heating it to 490 degrees Fahr., when its color is brown, and maintaining at that temperature until its color is bright blue." Mathews investigated this and found that when he tempered three pieces of steel at 790 degrees Fahr. for 8, 20, and 40 minutes the Brinell hardness numbers were 425, 390, and 340 respectively.

After the steel has been held at the proper temperature for the proper length of time it is generally immaterial how it is cooled. The common practice is to remove the pieces from the furnace or bath and cool in the air, although many steel treaters quench after tempering. There is one exception to the statement that it makes no difference how the material is cooled: a few alloy steels are prone to develop a condition known as blue-brittleness when cooled slowly from the tempering temperature. This condition which can be detected by the low resistance to impact does not develop when these steels are quenched.

⁴⁵Metallography and Heat Treatment of Iron and Steel, 1926, page 247.

STRUCTURAL CHANGES IN HARDENING AND TEMPERING

Before taking up the theories of hardening it will be of advantage to review some of the facts we have learned about hardening and tempering and to trace the structural changes taking place in these two operations. For illustrative purposes we will consider what happens in cooling a high carbon steel containing approximately 0.90 per cent carbon from above the critical range. This steel is, as we have seen, of eutectoid composition. In discussing the structural changes we will consider four quenching rates: the first, very slow cooling; the second, slow cooling; the third, fast cooling; and the fourth, very fast cooling. We will then consider tempering as applied to the structure resulting from each of the four treatments noted above. These four rates of quenching may be represented by cooling a small bar in the furnace, in still air, in oil and in cold water, corresponding to the formation of pearlite, sorbite, troostite and martensite.

Now consider the first case; very slow cooling. We heat a bar of high carbon steel to some temperature above 1300 degrees Fahr. (700 degrees Cent.), the A_{c1} point. At this temperature the steel is in the structural condition known as austenite. This, the solid solution of carbon or iron carbide in gamma iron, is stable above A_{c1} . If we permit this steel to cool slowly through the lower critical point A_{r1} all of the normal transformations will take place and the austenite will be transformed into pearlite.

This change upon slow cooling is pictured graphically in Fig. 58 adopted from Sauveur. Above the critical range the structure is austenite. As the steel slowly cools through the range the structural condition changes successively from austenite to martensite, troostite and sorbite, finally assuming the stable form pearlite. In this slow cooling the lower transformation point A_{r1} appears at its normal temperature, 1290 to 1300 degrees Fahr. There is some question as to whether high carbon steel in slow cooling from above A_{r1} actually does pass through successive stages where its structure is first martensite, then troostite, and finally sorbite, before it assumes the structurally stable pearlite. Some investigators believe that in slow cooling the austenite transforms directly into pearlite, but the evidence is preponderantly in favor of its passage through these three stages. This evidence rests on the established fact that it is possible to cool steel slowly through a portion of the critical

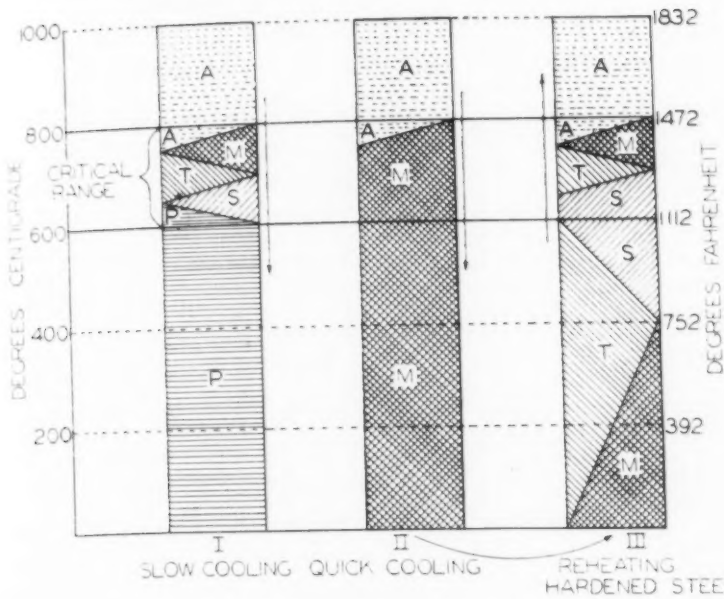


Fig. 58—Diagram Showing the Structural Change in Slow Cooling, Very Fast Cooling and Reheating after Very Fast Cooling. (Sauveur.)

range and then quench, with the result that martensite, troostite or sorbite will be formed depending upon the temperature from which it is quenched. Thus if we quench from the temperature corresponding to M, in Fig. 58 martensite will be formed, or troostite or sorbite if quenched from T or S in Fig. 58. The areas M, T and S are made purposely large in Fig. 58 in order that they may be readily plotted and differentiated. Actually each represents a relatively narrow range of temperature.

If we temper this slowly cooled steel what will happen? As the specimen was slowly cooled through the critical range all of the normal transformations have taken place, hence if we heat it nothing will happen until the critical range is reached where the steel will again pass through its normal transformation from pearlite stable below A_1 to austenite stable above the range. As pearlite represents a stable structural condition repeated heating and cooling below about 1300 degrees Fahr. will have no appreciable effect on the structure. The steel is already in stable equilibrium at atmospheric temperature and no thermal treatment will make it more stable.

Now suppose we cool this high carbon steel at a slightly accelerated rate, as for instance cooling a small bar in air. There is not sufficient time available for all of the normal changes to take

place. According to Fig. 58 the austenite changes successively to martensite, to troostite and finally to sorbite. The cooling rate is too rapid to permit the sorbite to change to pearlite and so the sorbite is retained at atmospheric temperature. As was discussed in a previous installment the accelerated cooling has also affected the position of Ar_1 point; it now occurs at 1200 to 1250 degrees Fahr.

We know that when cooling is accelerated the resulting structure is one of metastable equilibrium, the degree of instability depends upon the speed of cooling. We also know that when a steel which is in a metastable structural condition is reheated, sufficient plasticity is conferred upon the metal so that it tends to return to a stable condition. Sorbite is not so stable as pearlite but it is sufficiently near to stability so that when a sorbitic steel is tempered it transforms to pearlite with great difficulty, if at all. Hence we can heat a sorbitic steel from atmospheric temperature to the lower critical point with little or no change in structure. In fact sorbite can hardly be changed to pearlite unless the steel is heated into the critical range where austenite is formed and then followed by slow cooling.

It follows, then, that very slow cooling resulting in pearlite, or slightly accelerated cooling resulting in sorbite produces structural conditions that are stable or sufficiently stable so that they are unaffected by tempering. Continued heating to any temperature below the critical range will not affect the structure. There is, however, one exception to this. Some steels that are sorbitic in structure when heated to a temperature just below Ar_1 or just inside the range tend to spheroidize. This mechanism has been discussed before. We have seen that under the proper condition heating to near the critical range results in a structural condition in which the cementite has formed into globules or spheres instead of thin lamellae. If we look upon the familiar lamellar pearlite as the condition which steel assumes when it is in stable equilibrium, then we can say that sorbite, too, is relatively stable because tempering does not result in the transformation of the sorbite into lamellar pearlite.⁴⁶

Let us now view the structural change in very rapid cool-

⁴⁶Speaking correctly, spheroidized cementite represents a more stable structural condition than lamellar pearlite but in the present discussion is not so considered, as it does not result from normal changes taking place when the steel is cooled through the lower transformation point.

ing. Referring to the second diagram in Fig. 58 we see that very rapid cooling results in the transformation of the austenite stable above the critical range to martensite. This condition represents the first stage of the normal transformation from austenite to martensite to troostite to sorbite to pearlite, and is the most unstable condition possible to attain under normal quenching conditions. In this rapid quenching the position of Ar_1 has been lowered from 1300 degrees to approximately 600 degrees Fahr.

What happens in tempering this unstable martensite is shown in the third diagram in Fig. 58. As soon as the specimen is heated a slight plasticity is conferred upon it and the unstable martensite starts to transform into the more stable troostite. At approximately 750 degrees Fahr. (400 degrees Cent.) the martensite has been converted and the structure is wholly troostite. As the material is heated further the troostite starts to change into the still more stable sorbite, which change is not complete until the critical range is reached, as is evident from Fig. 58. Heating through the range causes a rapid change in structure from sorbite to troostite to martensite and finally to austenite. Now if the specimen is again cooled these changes will take place in the reverse order and the resulting structure will be pearlite, sorbite, troostite or martensite depending upon the speed of the cooling.

If the steel is cooled at a rapid rate from above Ar_1 but not fast enough so that martensite is formed, the structural changes taking place will be as follows. In the critical range the austenite will be transformed into martensite and this in turn to troostite. The cooling is too rapid to permit a further change to sorbite or pearlite and the troostite will be retained at atmospheric temperature.

If this troostitic steel is reheated in tempering there will be no structural change until a temperature of 750 degrees Fahr. (400 degrees Cent.) is reached. At this temperature there is sufficient plasticity in the metal so that the structural change from troostite to sorbite begins. This change continues as the material is being heated to the critical range. In the range the rapid change from sorbite to troostite to martensite to austenite occurs, and above the range the specimen will consist wholly of austenite stable at this temperature.

Let us trace these changes by means of the photomicrographs shown in Figs. 59 to 66. The specimens were prepared as follows:

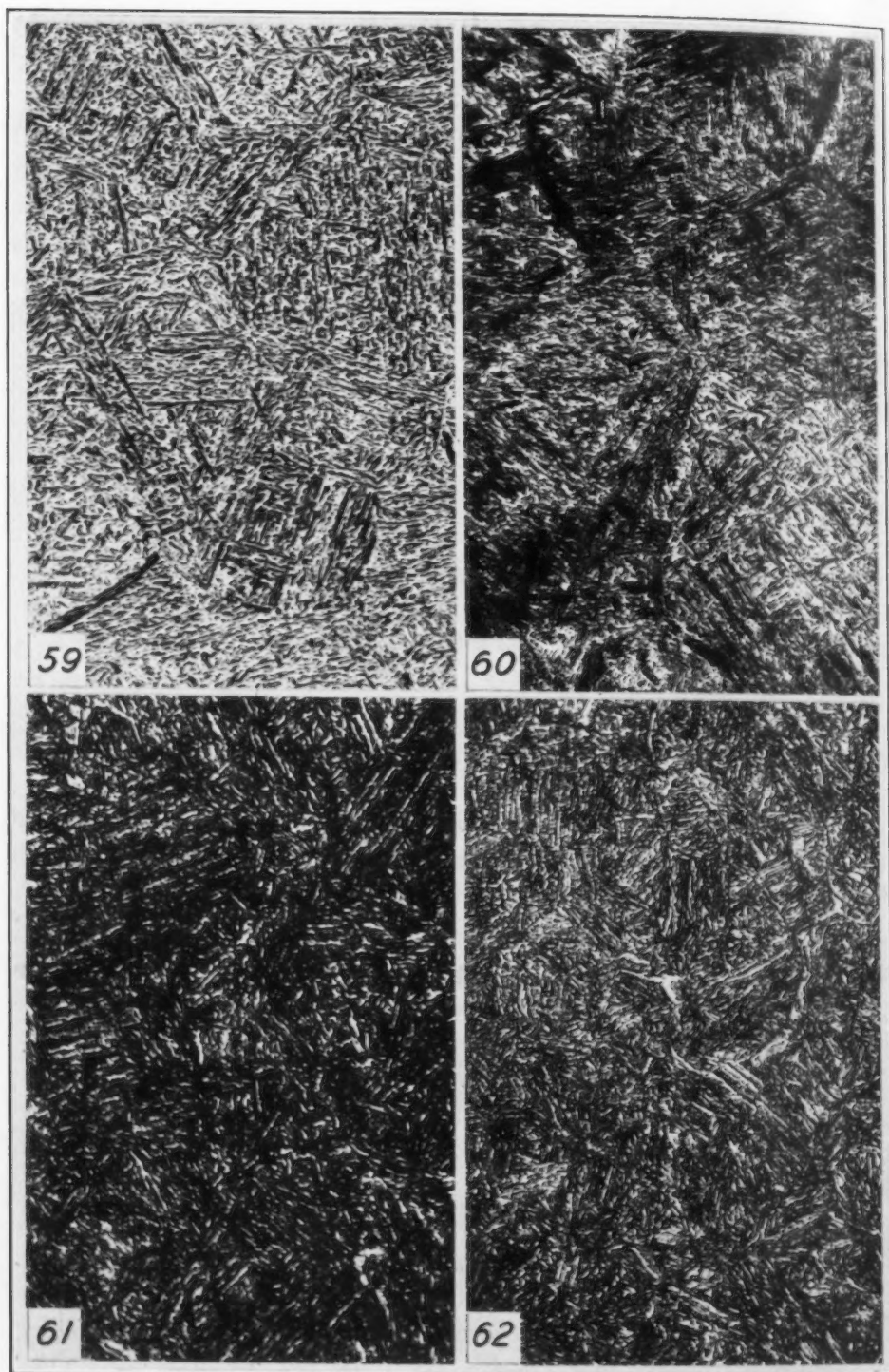


Fig. 59—Quenched in Ice Water. Martensite. Scleroscope Hardness 83. Fig. 60—Quenched and Tempered at 200 Degrees Fahr. Martensite and a Little Troostite. Scleroscope Hardness 78. Fig. 61—Quenched and Tempered at 400 Degrees Fahr. Troostite and Probably Some Martensite. Scleroscope Hardness 63. Fig. 62—Quenched and Tempered at 600 Degrees Fahr. Troostite. Scleroscope Hardness 56. All Photomicrographs $\times 500$. All Etched in Alcoholic Nitric Acid.

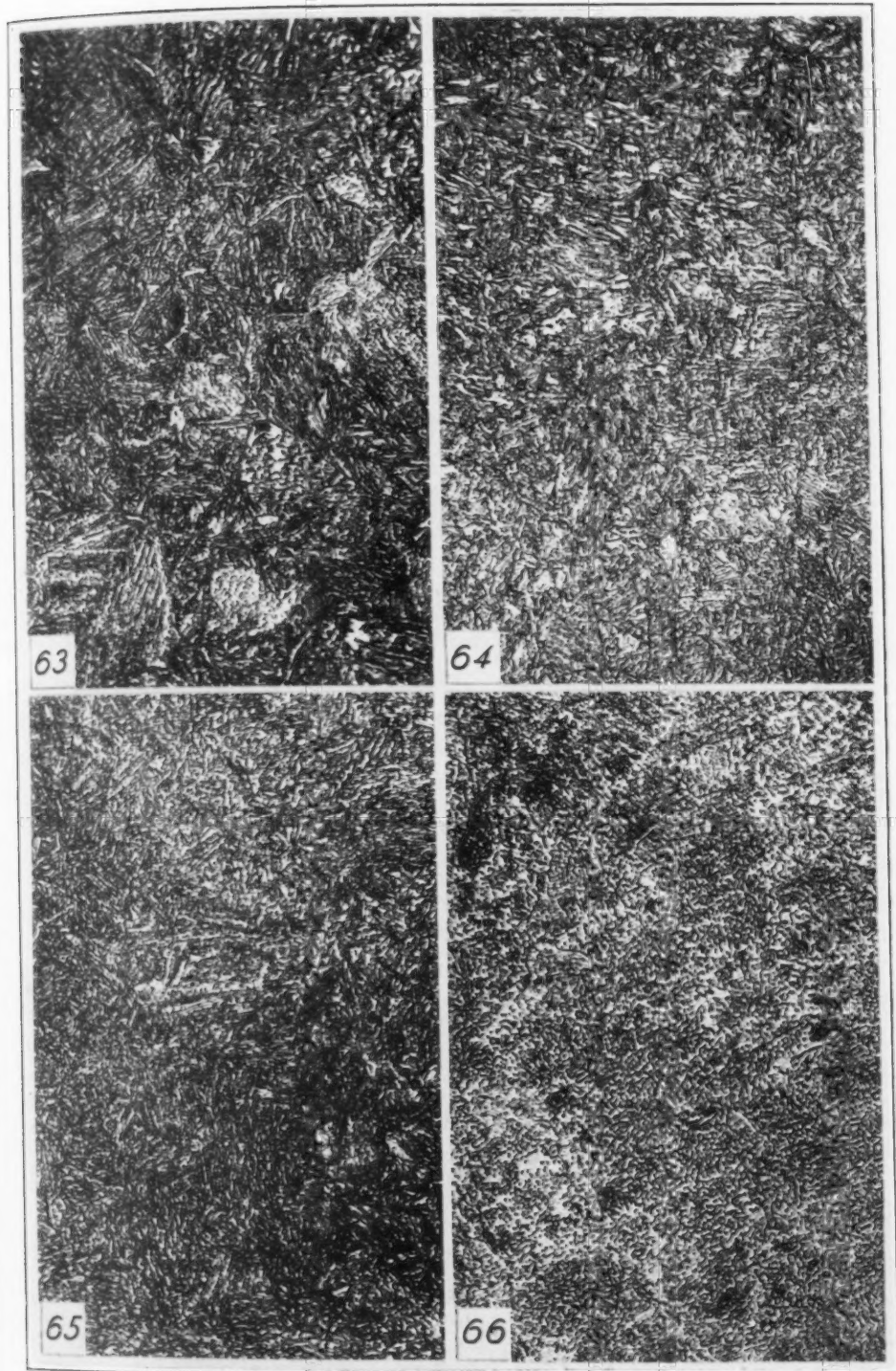


Fig. 63—Quenched and Tempered at 800 Degrees Fahr. Troostite and a Little Sorbite. Scleroscope Hardness 47. Fig. 64—Quenched and Tempered at 1000 Degrees Fahr. Sorbite and a Little Troostite. Scleroscope Hardness 38. Fig. 65—Quenched and Tempered at 1200 Degrees Fahr. Sorbite. Cementite Starting to Spheroidize. Scleroscope Hardness 31. Fig. 66—Quenched and Tempered at 1400 Degrees Fahr. Cementite Practically all Spheroidized. Scleroscope Hardness Very Low. All Photomicrographs $\times 500$. All Etched in Alcoholic Nitric Acid.

A $\frac{1}{2}$ -inch bar of annealed tool steel containing 0.96 per cent carbon, 0.31 per cent manganese and 0.52 per cent chromium was heated to 1950 degrees Fahr., held for 15 minutes and quenched in ice water. The bar was broken into small sections and specimens tempered for 15 minutes at the temperatures noted under the respective photomicrographs. The specimens were cooled slowly in the furnace from the tempering temperature. A quenching temperature of 1950 degrees Fahr. instead of the normal temperature of 1400 degrees Fahr. was used in order to promote grain growth and thus accentuate differences in structure due to tempering.

The quenched structure, Fig. 59, is typical of martensite, although had the quenching temperature been lower the particles would have been much smaller. Even though the quenching was drastic there is probably a little troostite⁴⁷ present as the hardness of pure martensite is close to 100 scleroscope. Fig. 60 shows that tempering at 200 degrees Fahr. results in the formation of an appreciable amount of troostite as it is plainly evident in the microstructure. The difference between this structure and the martensite shown in Fig. 59 is clear. In Fig. 61 tempered at 400 degrees Fahr. the structure is mostly troostite. This was very evident from the speed with which this specimen etched and also from the much lower hardness. The softening effect of tempering at 200 and 400 degrees Fahr. is considerable. The hardness has decreased from 83 to 63. Except for the coarseness due to the high quenching temperature, the structure shown in Fig. 61 is fairly representative of the average heat treated tool steel.

Further tempering results in a marked reduction in hardness but the effect upon the microstructure is not great as is clear from comparing Fig. 62 tempered at 600, Fig. 63 tempered at 800, and Fig. 64 tempered at 1000 degrees Fahr. These temperatures are in the range where sorbite is formed. Fig. 64 is more typically sorbitic than Fig. 62 or 63.

Fig. 65 is the specimen which was tempered at 1200 degrees Fahr. Theoretically this structure should be wholly sorbite. Actually an appreciable amount of spheroidization had taken place; which was more pronounced near the surface of the specimen than in the area photographed as Fig. 65. The specimen whose structure is shown in Fig. 66 was tempered at 1400 degrees Fahr. followed

⁴⁷It is very possible, also, that the structure in Fig. 59 contains some retained austenite which would account for the relatively low hardness.

by slow cooling. This temperature is above A_{c1} and is within the annealing range. Theoretically the resulting structure caused by slow cooling from this temperature should be laminated pearlite. Actually as shown in Fig. 66 the cementite has spheroidized completely, no laminated pearlite is present. It was not possible to obtain accurate scleroscope readings on this specimen but it was very soft, probably about 160 Brinell number.

SUMMARY OF STRUCTURAL CHANGES IN TEMPERING

From the standpoint of equilibrium varying the rate of cooling a piece of high carbon steel produces a structural condition which is most unstable when cooled most rapidly. Instantaneous cooling would result, theoretically, in depressing the transformation range to atmospheric temperature or below, which means that the austenite stable above the critical range would be retained at atmospheric temperature. This is the most unstable structure possible. Only a very small amount of reheating would be necessary to promote the transformation of the extremely unstable austenite into a more stable structural condition.

Very fast cooling depresses the critical range from its normal temperature of 1300 degrees Fahr. to approximately 550 degrees Fahr. This means that only sufficient time is available for the austenite to transform into martensite which is retained at atmospheric temperature. In normal quenching practice martensite is the most unstable structural condition possible to retain at atmospheric temperature. It is so stable that the slight plasticity conferred by but little heating permits it to change into the more stable troostite. As a quenched high carbon steel is tempered the change from martensite to troostite begins immediately and is complete at 750 degrees Fahr. (400 degrees Cent.). During the reheating of this rapidly cooled steel from atmospheric temperature to 750 degrees, it becomes less and less hard and more and more ductile. At 750 degrees Fahr. the change from troostite to sorbite begins and continues as the material is being heated from this temperature to the critical range. As the heating is continued it becomes less hard and strong and more ductile and tough, as the harder troostite transforms into the softer sorbite.

Moderately fast cooling, as for example, quenching a $\frac{1}{2}$ -inch bar in oil depresses the critical point from its normal temperature

of 1300 degrees to about 1100 degrees Fahr. This means that sufficient time was available for the austenite to change to martensite and then to troostite, which is retained at atmospheric temperature. Troostite is more stable than martensite, so much more so that there is no structural change in reheating until a temperature of about 750 degrees Fahr. is reached. At this point the transformation of the troostite into sorbite begins. This continues as the temperature is increased from 750 degrees Fahr. to the critical range. If the structure after quenching is troostite there will be no change in structure and no appreciable change in properties in reheating this steel below 750 degrees Fahr. If heated above this point the hardness and strength decreases and the ductility increases as the material becomes more and more sorbitic with increasing temperatures.

Slow cooling, as for example a $\frac{1}{2}$ -inch bar of tool steel cooled from above the critical range in air depresses the A_1 point from 1300 degrees Fahr. to about 1200 degrees Fahr. In this relatively slow cooling sufficient time is available for the austenite to change to martensite and then to troostite and finally to sorbite, which is retained at atmospheric temperature. Reheating this steel for tempering produces no structural change below the critical range hence the structure and its accompanying properties resulting from this air cooling will not be altered by reheating to any temperature below A_1 point.

Very slow cooling from above the critical range results in all of the normal transformations taking place, i. e. austenite to martensite to troostite to sorbite to pearlite. This is a change in structure from austenite stable above the range to pearlite stable at atmospheric temperatures. Since there is no metastable condition resulting from this slow cooling tempering will have no effect on the structure or properties.

In addition to the changes in structure and properties caused by tempering quenched carbon steels, this reheating also serves to relieve the strains induced by the rapid cooling. Hence all steels which have been rapidly cooled should be tempered to the degree that hardening strains are relieved, even though extreme hardness and strength are desired.

REFRACTORIES AND HEAT INSULATION IN CONNECTION WITH FURNACE DESIGN

BY GUY A. BARKER

Abstract

The author pictures the change in furnace design from the great masses of brickwork to the modern thin-walled heating machines. It is shown that a thin wall of the new insulating materials will transmit less heat than a very much thicker wall of solid refractory material. Refractory cements and their function in cutting down heat losses and protecting refractory linings are quite thoroughly discussed.

THE economies which have resulted from the use of heat insulation, its effect on refractories used in furnace construction, and the resultant changes that may be anticipated in furnace performance, have aroused new interest among furnace designers and users, especially in view of the improvements that are being brought about in the manufacture of high grade refractories and accessory materials.

The old fashioned idea of furnace design was great masses of brickwork, with arches thrown up this way and that to take care of any opening that might be necessary. Heat was applied in an arbitrary fashion with the intention of supplying the total number of heat units that would be required, and dependence was placed on soaking effects to bring about such uniformity of temperature as could be had. On higher temperature furnaces, great deterioration took place in the brickwork, but this was anticipated and to some extent offset by the thickness of the walls.

With improvements in refractories during the last quarter century furnace walls have been made thinner and thinner. Steel has been developed for structural support to replace piles of masonry; suspended arches have come into vogue, firing and heating methods have been improved, and definite principles of design have been brought into play in connection with combustion

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chambers and heat transference. Recently the use of alloys for conveyor belts, guide rails, etc., together with mechanical pushers, feeders, carriers and dischargers, have tended to put modern industrial furnaces in the class of machines.

It is needless to say that under the old regime very little insulation was used. In the first place suitable furnace insulating materials were not available. In the second place the thick walls to a small extent took the place of insulation by offering with each nine inches of thickness of brick about the same resistance to heat flow as would be accomplished by one inch of good furnace insulation.

The thick walls operated at their greatest disadvantage when used on intermittent furnaces. On continuous furnaces it was found to take months before heat flow in the walls and hearth became sufficiently constant to justify the assumption that furnace temperature conditions were reasonably stable. Therefore, the natural and logical consequence of intermittent operation was a continued state of varying furnace conditions. Besides limiting the character of work that could be turned out from such furnaces, the further result was great wastage of heat by allowing the heavy walls to soak it up only to dissipate it again when the furnace was shut down.

In present day practice, it is still true that heavy-duty furnaces require thicker walls of brick than in the case where refractory conditions are less severe, yet they are much thinner than were formerly used. Today it is an unusual condition, where a high wall is combined with a heavy load or high temperature, that really demands a brick wall thickness of even 22.5 inches. A good average thickness of refractory for ordinary furnaces is 13.5 inches, but the average should be less for markedly intermittent operation. Where walls are thin and circumstances demand, the brick can be tied to the buckstays to prevent "walking".

Better grades of firebrick and special brick for particular applications are largely responsible for the modern trend as above described. Much development work is still to be done, but progress is being made, and on this progress is dependent the entire future course of furnace economy. Designers are at work improving heating equipment, and refinements are being made in types and methods of building furnaces, but the limitations of all seem to be defined

by the limitations of the furnace brickwork. There is a continual demand for better and better refractories.

The Function of Insulation: The growth and development of insulation suitable for use on furnaces has been coincident with that of the refractories in connection with which it is used. The necessity for materials designed to retard heat flow arose as a corollary to the use of thinner walls of better grade brick as well as increasing demands for higher efficiencies.

The fact that it is far more preferable to minimize heat losses by the use of insulation rather than by using very thick walls is emphasized by this illustration: An 18-inch firebrick wall insulated with a 4-inch thickness of high grade insulation will transmit less heat than a solid refractory wall 60 inches thick.

The first reason which appears to require that insulation be used is accounted for by the desirability of limiting heat flow from the hot interior of the furnace, in order to reduce the fuel expenditure necessary to maintain the furnace temperature. Raw fuel has steadily increased in price during recent years, and modern construction has eliminated the great thickness of brick that formerly tended to cut down heat loss. Both of these factors point directly toward the use of an efficient material to bar the flow of heat from inside of walls and arches. When it is considered that heat loss from one square foot of bare surface often amounts to a matter of dollars per year, the proper emphasis begins to be laid on insulation which will save a major portion of this loss.

As an example, suppose a 2400-degree Fahr. furnace with 18-inch firebrick walls is uninsulated and operates continuously in such a manner that the worth of furnace heat is \$0.40 per million B. t. u.; the dollar equivalent of the heat loss then amounts to \$2.67 per square foot per year. When these walls are insulated with 3 inches of a better grade high temperature block this loss is reduced to \$1.21 and the saving is \$1.46 per square foot per year. In such a case the investment represented by the cost of the insulation is repaid by the savings in operating cost long before the end of the first year's use.

The heat that is retained in the walls by virtue of the insulation works to raise the mean temperature of the refractories. This minimizes the temperature differential between inside and outside of the brick which lessens internal strains and reduces spalling

effects. Akin to this are the fewer and smaller wall cracks that appear due to uneven expansion and contraction.

Insulation itself, if properly applied, tends to seal cracks in furnace walls, thereby operating to prevent the infiltration of air or the extrusion of furnace gases. In some applications this feature is of even more importance than the saving of heat and reduction in fuel cost.

When insulation is placed over the exterior of furnace brickwork, resistance is introduced in the path of heat flowing directly to the outside. This promotes heat flow along the length of the walls and cooler portions of the furnace are raised to a higher temperature. Sharp temperature changes are obviated and adjacent brickwork is protected against widely varying rates of expansion. Lower temperatures may be used in the heating zone and still adequate temperatures maintained throughout all portions of the furnace setting. This saves fuel and still further prevents deterioration of the refractories.

The idea of blanketing a furnace with nonconducting materials in order to keep in the heat is neither startling nor novel. Recently, however, designers have been making new applications of old theories, and great success has attended the special use of insulation on those portions of a furnace which tend to remain at lower than mean temperature.

It is usually true that the capacity and efficiency of a furnace or boiler are directly dependent upon the operating temperature. With the improvements that have taken place in refractories, and the protection against internal stresses afforded to the brickwork by insulation, we find a recurrence of efforts to carry on various processes at higher and higher temperatures. Here again we are limited by the heat resisting properties of the refractories that are available, but the tendency seems to be in the direction indicated.

However, increase in production and improvement in quality of product do not wait upon the use of increased temperatures. The saving of heat, the uniformity of temperature, and the elimination of air infiltration, which may be obtained through insulation have, in many industrial processes, resulted in attainment of both these advantages. It is also frequently possible to make a material saving through decreased waste of product and by doing

1929

away with accessories that were introduced in the attempt to accomplish in an old fashioned furnace the results that are possible in a properly insulated one when the material is handled directly on the hearth.

Besides the above factors, which depend upon insulation, there is an important human advantage of localizing the heat in the furnace where it is used. The statement that the efficiency of workers is impaired at temperatures above 64 degrees Fahr. has become trite, but the fact remains that insulation used to accomplish certain definite results as above outlined finds further justification in human comfort.

The Function of Refractory Cements: A discussion of means and methods for protecting and extending the life of refractories would be incomplete without some mention of improvements that have been made in the last twenty years on the bonding of brick. During this period refractory cements were originated, developed, tried and proven to be of great importance in reducing maintenance of refractories.

In best furnace practice a material is needed to bond the bricks as well as take up irregularities of shape. Fireclay is merely a filler and has no bonding strength or high temperature resistance. It shrinks badly, crumbles away and blows out of the joints, exposing the edges of the bricks to the action of flame and ash. The evil effects of this exposure are apparent to anyone who has looked inside a furnace setting.

By the use of a suitable refractory cement, several notable advantages are brought about. Heat losses are cut down by eliminating the open joints between the bricks. This further assists in protecting the insulation from furnace gases or vapors. Air which might otherwise be drawn in through the walls is excluded by the tight setting which results from application of a strong cement.

A furnace wall may be made to stand up against higher temperatures than the bricks themselves would otherwise withstand if heat is prevented from entering the setting through cracks, thereby softening the bricks at some distance from the surface. Open joints also increase spalling effects, because there is no possibility of an even temperature gradient from one face to the other.

In applications where there is a tendency toward clinkering, the formation of bad deposits on the setting may be retarded by making surfaces as smooth as possible. Open joints give the clinker a good hold and in removing it the bricks of the setting are often pulled out unless they are strongly bonded together. Wash coating the interior of the furnace chamber with a suitable refractory cement goes a long way in the mitigation of clinkering difficulties.

The erosive action of oil flames and the slagging of brick by low fusion ash are items of great concern. A setting with tightly sealed joints of strong refractory cement and brick pores filled by wash coating is the best protection that it is possible to obtain.

Where refractories are spalling or melting away, the deterioration may be slowed down considerably by a $\frac{1}{4}$ to $\frac{1}{2}$ inch plaster coating of the proper refractory cement bonded directly to the interior of the setting. Walls whose life could be measured by weeks have thus been made to last many months.

If the brickwork has failed locally, instead of replacing the destroyed brick, it is frequently economical to make a hole in the setting and pound in suitable plastic firebrick material. Pit fires, small ladles, certain induction furnaces and similar equipment is usefully served with rammed-in monolithic linings of a proper refractory cement.

Where bricks are being laid up with refractory cement the joint is best protected by troweling the cement on the brick already placed, then laying the brick on top and tapping until the joint between the bricks is the desired thickness, being sure there is sufficient cement that some of it squeezes out between the edges of the brick. This extruding cement should be troweled back over the face of the joint and brick to make a "T" joint for the protection of the edges. For brick to brick joint thin refractory cement is used, and all faces of the brick, that will come in contact with brickwork already in place, are dipped in this mixture of soup consistency.

The cost of the better grades of refractory cements (the only ones economical to use) is about 5 or 6 per cent of the total cost of the setting. It only takes a few weeks of increased life of the brickwork to retire this investment, and the usual effect of the proper application of suitable refractory cements is to lengthen the life of a setting by many months.

Quality and Adaptability of Materials: In the matter of particular refractories which are peculiarly adapted for special uses we may only recall a few of the basic principles.

A suitable refractory should not only resist the temperature of the process but also the chemical action of whatever materials come in contact with it. It must be strong enough to stand up in the setting and resist the incidental abrasion and impact. Expansion or contraction which occur with temperature change should be uniform and not too great.

Firebrick made from alumino-siliceous clays are predominant in manufacture and use. Their relative cheapness makes them common even when their acid character is disadvantageous. Such bricks are strong and resist temperature changes well, but are subject to shrinkage under some high temperature furnace conditions.

Silica bricks have as one of their principal characteristics a material expansion in the temperature range where firebricks contract. They are, therefore, particularly useful for crowns and arches and in other places where absence of shrinkage is important. Silica bricks are very refractory and markedly acid, but spall badly with rapid changes in temperature, as a result of which they are not used on discontinuous furnaces.

Probably the most important basic brick is magnesia. Commercial magnesia bricks are suitable for furnace linings up to temperatures of 2900 degrees Fahr. This product has important use in the lining of basic open-hearth furnaces for copper and steel.

For temperatures up to 2750 degrees Fahr. one of the popular neutral refractories is made from chromite. Chrome bricks are practically without reaction to either slags or silica. Chromite also has application as a patching material.

The carbide and high grade alumina which have shown such remarkable refractory properties are constantly gaining in favor where special uses can profit by their peculiar characteristics. Refractories in general are gradually being looked upon as something more than substances difficult to fuse.

In the matter of insulating materials for furnace work, the principal considerations are insulating value, adaptability, durability, price and temperature range within which suitable physical

characteristics are maintained. Several different forms of insulation are available on the market, such as blocks, bricks, cements and filling materials. Generally speaking, the proper use of insulating cements is limited to finishing purposes for the protection of the surface. Sometimes they are applied as a special sort of filling material.

Filling materials of whatever sort are properly utilized where conditions render impractical the use of solid insulation such as blocks or bricks. The better grades of solid insulation are wholly reliable as to quality, conductivity, strength and stability in service. Filling materials depend chiefly upon the human element for their proper application. Even the most careful use of filling materials will not insure stability or overcome settling in service.

The convenient sizes of block insulation (6" by 36" or 12" by 36") decrease the cost of applying the material, and reduce heat transmission through the insulating, because the number of joints is minimized, and in two-layer work through-joints are practically eliminated.

The kind, quantity and methods of application of materials which are to be recommended for particular furnaces, requires a detailed treatment that is beyond the scope of this paper.

In the matter of refractory cements, there are certain basic considerations which should be touched upon in summarizing the qualities required to accomplish the results previously described.

A suitable cement should have a base similar to the brick used in the setting, and should be chemically inert to the action of the furnace.

It should have a temperature resistance equal to or better than that required of the brick, and should bond firmly without undue shrinkage. The cement should be readily workable and ordinarily should not vitrify until exposed to furnace heat, in order to allow for readjustment that takes place in the setting during the initial firing.

All of the correlating properties of insulation, of refractory cements and of refractories themselves, when taken to advantage in the most approved manner, operate to place at the disposal of the modern user of industrial furnaces a production which, as to quantity, quality and economy, was literally unheard of prior to the last decade.

Comment and Discussion

Papers and Articles Presented Before the Society and Published in Transactions Are Open to Comment and Discussion in This Column

DISCUSSION OF THE PAPER BY H. P. RASSBACH ON "THE MANUFACTURE OF ACID OPEN-HEARTH STEEL FOR FORGING INGOTS"

By P. B. PARKS²

THE writer considers Mr. Rassbach's paper an excellent account of the practical manipulation of an acid open-hearth steel plant, and having had considerable experience in steel-making in Sheffield, he would like to add a few remarks which he thinks might be of interest to the author. The writer would like it to be remembered that he has had no experience of open-hearth steel-making on this continent and he therefore, realizes that some of the following methods and suggestions may, owing to local conditions, be quite impracticable.

THE CHARGE. As stated by the author, the carbon content of the bath when clear-melted is of great importance and often has a real influence on the final condition of the ingots. The writer likes to see a 50-ton Siemens melt with a carbon about 0.50 per cent above specification; the "boil" should then be reached in about an hour and a half, and the heat be in condition to tap from four to five hours later. This may sound somewhat idealistic, but it can be more or less regularly approached by scientifically designing the charge, the pig and scrap having been graded. For "hards," that is steels of 1.00 to 1.50 per cent carbon, such as files and spiral springs, the charge should contain 40 to 50 per cent of pig iron, whilst for steels of 0.25 to 0.75 per cent carbon, 25 to 33 per cent of pig is used in proportion; for special tires, silico-chromium springs, and nickel-chromium steels only about 10 per cent ordinary pig iron is used with 20 to 30 per cent of special hematite pig, according to the carbon specification.

The writer agrees that the practice of "pigging-back" should be deprecated; in fact, rather than do this he has often changed the heat to something having a lower carbon specification, provided the pit can be got ready in time if different molds are required. Every Siemens manager should be authorized to do this and be provided with a selection of useful specifications to which he can change in circumstances of this nature.

The author does not state the actual method of charging, although he mentions later the cutting effect of iron-oxide on the hearth. The writer's experience is that if enough pig iron is charged first to completely cover the

¹H. P. Rassbach, "The Manufacture of Acid Open-Hearth Steel for Forging Ingots," *TRANSACTIONS, American Society for Steel Treating*, Vol. XV, February, 1929, p. 289.

²P. B. Parks, member of the society, steel-maker and works metallurgist for the Riverside Iron Works, Limited, Calgary, Alta.

bottom and banks, very little harm can come to them from rusty scrap. With mechanical charging machines this can easily be done.

WORKING THE HEAT. The author here mentions that "small additions of limestone are effective at this point." The writer would like to qualify this by stating that lime should be added freely at this stage. He considers it has both a beneficial and economical effect, as it not only enriches and increases the fluxibility of the slag, but by displacing the iron oxide from the slag into the bath, has the effect of reducing the carbon in the same but in a much safer manner, as an addition of ore would do. The effect of limestone on the slag can be well expressed by the following formulae which are based on the average of numerous analyses.

Normal acid slag at commencement of "boil":

FeO	MnO	SiO ₂
55%		45%

After generous limestone additions:

FeO	MnO	CaO	SiO ₂
	38%		62%

FINISHING THE HEAT. The writer found that in most cases it was advisable to let the carbon fall a few points below the mean of the specification limits before "going on," especially when the carbon was dropping gradually. The addition of the finishings themselves, which, including the silicon condition, whilst the few points lacking are supplied by the ferromanganese to follow. When the carbon is falling rapidly or erratically, through over-doses of ore, or lack of condition in the slag, this risk cannot, of course, be taken. The addition of the finishings themselves, which, including the silicon manganese and chromium, often amount to well over a ton, is sometimes sufficient to knock the bath out of condition if added cold, and for this reason the writer always had the "lumps" preheated in a small oven by the side of the furnace. They were then simply pulled out at a bright red heat on to the stage and shovelled into the bath. Ladle additions of any kind should be avoided except in cases of extreme necessity, such as furnace trouble beyond the melter's control or "hard taps." In the latter case, when there is good reason to believe that the carbon has dropped on account of the excessive delay, carburizing in the ladle may be attempted with powdered anthracite coal added in paper bags. The efficiency per cent and the even distribution of the carbon are both very problematical and at the best it is merely an optimistic compromise.

CASTING. The writer is an enthusiastic disciple of bottom-pouring, and believes that wherever possible it should be employed. Whilst at one Sheffield Works, he superintended a great number of casting experiments with a view to arriving at perfect ingot production. The external dimensions of the molds used were 14 inches square at the top tapering down to about 8 inches square at the bottom. They were grouped in sixes around a trumpet or "guit" which was connected by a system of runner bricks to the bottom of each mold. This, I take it, is similar to the arrangement mentioned by Mr. Rassbach.

The molds were surmounted by a patent feeder-head, of the writer's own design (vide *Iron Age*, July 11, 1918) the whole system being thoroughly cleansed by means of suction pipes.

The writer believes that too much importance cannot be attached to the rate of casting, and he well remembers standing over the teemer making him take a definite length of time to cast each group of ingots. Each ingot weighed about 2500 pounds, so that each bed of six molds together with gait and runners required about seven tons of molten steel. The objects aimed at were perfect ingot skins, absence of transverse "clinks" or stresses, and reduction of pipe areas. The teeming speeds, varied, of course, with the type of steel being cast, but for ordinary medium carbon steels, the optimum speed was $4\frac{1}{2}$ to 5 minutes per bed. Consequently for 50-ton heat, over half an hour is taken for casting alone, which, together with the time absorbed during tapping and moving the ladle from cluster to cluster, means that molten metal is in the ladle fully three-quarters of an hour. Since, in Europe, both the furnacemen and pitmen are paid on tonnage of good ingots produced, everyone concerned is anxious to get the metal into the molds, and the Siemens manager does not often get all the co-operation desired. The tendency of the sample-passer is to tap too hot, and the teemer to cast too quickly or with too large a nozzle, and all these factors must be rigorously controlled if the production of first-class ingots is desired. With some special steels, principally produced in a 12-ton electric furnace, as long as $7\frac{1}{2}$ to 8 minutes were taken to cast a cluster, but here, of course the smaller tonnage meant a correspondingly shorter time for the steel in the ladle. With these slow speeds there is a tendency for the steel to freeze over when coming up the molds, but with an ever increasing cross-section, the "kish" as we called it, can be kept moving by being agitated with wooden laths, thus preventing over-lapping which must not be allowed to happen. When the steel has entered the feeder-head, if violently agitated with the laths, it will be found possible to feed the cluster, still through the gait, of course, for quite an appreciable time, with the result that 90 per cent, often even 100 per cent, of the pipe is contained in the head. The writer had a considerable number of such ingots sawed completely through longitudinally in order to prove this and records and photographs of them are still at the works in question.

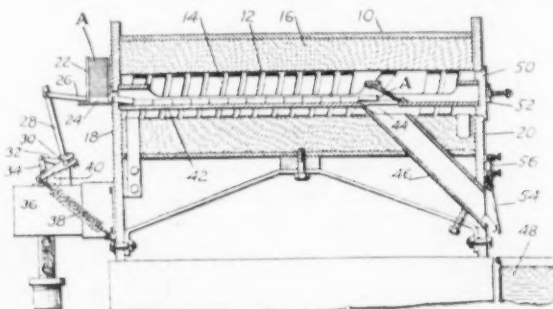
In conclusion, the writer would like to add that he finds Mr. Rassbach's paper extremely interesting, and that he hopes he may, in the near future, have the opportunity of further discussing a subject which is so peculiarly interesting to both.

Reviews of Recent Patents

By NELSON LITTELL, Patent Attorney
475 Fifth Ave., New York City—Member of A. S. S. T.

1,697,811, Jan. 1, 1929, Apparatus for Heat Treating, John B. Dailey, of Detroit, Michigan.

This patent describes a heat treating apparatus comprising a furnace 16 which is wound of metallic coil 14 which provides for a heat and a magnetic field inside the furnace. The articles A to be heat treated are pushed one by one in the chamber 42 of the furnace by the reciprocating push rod 26. When the articles A reach the discharge chute 44, if they have not been heated sufficiently to lose their magnetic properties, that is,



if the articles have not reached the critical temperature, they are retained by the surrounding coil and prevented from discharging. If the article A has reached the critical temperature, it is dropped through the chute 46 and into the quenching tank 48. As it emerges from the chute, it operates the flap valve 54 which controls the switch 56 to operate the solenoid 36 controlling the actuation of the push rod 26 which pushes another article into the furnace.

1,703,630, Feb. 26, 1929, Sheet-Steel Annealing, Paul A. Meehan, of Cleveland, Ohio, Assignor to American Dressler Tunnel Kilns, Inc., of Cleveland, Ohio, a corporation of New York.

This patent describes a method of preventing fusion or sticking together of steel sheets undergoing annealing in a tunnel kiln by sprinkling kieselguhr, diatomaceous earth or other inert and chemically inactive material between the sheets to keep them separated during the annealing operation.

1,695,594, Dec. 18, 1928, Steel and Method of Making the Same, Frederick C. Langenberg, of New York, N. Y. and Marcus A. Grossmann, of Canton, Ohio.

This patent describes a new extra low carbon steel of an effervescent character as distinguished from a killed steel. The invention is based on the discovery that tendency of extra low steel towards red shortness and

toward rusting is not due to the presence of sulphur or other impurities, but is due to the oxygen in an uncombined form in the intergranular spaces. The oxygen is removed from the effervescent steel by first melting the base material with suitable slag to reduce the carbon below .05% and then adding manganese in the form of a ferrous alloy to reduce the oxygen content of the finished steel below .03%.

1,700,460, Jan. 29, 1929, Metallurgical Process, John H. White, of Cranford, New Jersey, Assignor to Bell Telephone Laboratories, Incorporated, of New York, N. Y., a corporation of New York.

An object of this invention is to produce nickel and alloys of nickel which are uniformly forgeable. This object is accomplished by first treating the nickel with a small amount of vanadium followed by a small amount of magnesium. The vanadium has a greater affinity for sulphur than nickel and breaks up the nickel sulphide to form vanadium sulphide which is believed to be entrapped within the grains of the nickel and thereby prevents brittleness and permits uniform forging of the nickel and nickel alloys. The vanadium is preferably added as an alloy consisting of 25 per cent vanadium and 75 per cent nickel in an amount sufficient to make the total vanadium content of the bath about 0.25 to 0.50 per cent.

1,700,739, Feb. 5, 1929, Preparation for Cleaning Metal Preparatory to Painting, James D. Klinger and Clete L. Boyle, of Detroit, Michigan.

This patent describes a preparation for cleaning metal preparatory to painting in which mono-ethyl ether of ethylene glycol is used as a solvent for the oil and grease. In about 35 per cent by volume to 30 per cent of water and 35 per cent of orthophosphoric acid, the metal to be cleaned is preferably sprayed or painted with the cleaning solution and after a short period of time the cleaning solution is rinsed from the metal with hot water.

1,707,570, Feb. 12, 1929, Process for Toughening and Hardening Taps for Cutting Screw Threads, Milling Cutters, and Other Cutting Tools, Reginald Frank Knight and Frederick Lynch, of Burnham, England.

This patent describes a process of toughening and hardening taps which comprises drilling a hole through the center of the tap prior to hardening, filling this hole with clay or other suitable filling material, hardening the tap by heating and quenching, then removing the clay filling from the center hole and introducing a heating element into the hole to heat it to a sufficient degree to restore the center of the tap to its original soft condition.

1,703,442, Feb. 26, 1929, Ingot Mold, David J. Giles, of Latrobe, Pennsylvania, Assignor to Latrobe Electric Steel Company, of Latrobe, Pennsylvania, a corporation of Pennsylvania.

This patent discloses that a mold for casting steel ingots, when formed of cast iron alloy containing from 0.25 to 3 per cent of chromium, has a much longer life, resisting welding and furrowing of the mold walls by the molten steel than the ordinary cast iron ingot molds. The average cast iron ingot mold lasts approximately 55 heats, whereas a mold made of

cast iron containing 3.67 per cent carbon and 1.32 per cent chromium has been used for 180 castings of steel and is still in serviceable condition, and other molds made of cast iron containing 3.72 per cent carbon and 0.89 per cent chromium have been used for an average of 110 castings of steel before being materially affected by the molten steel.

1,704,086, Mar. 5, 1929, Method of Cleaning and Annealing Metal, Noak Victor Hybinette, of New York, N. Y.

This patent describes a method of cleaning metallic nickel and nickel alloys of chromium and the like from the relatively insoluble coating of oxides by subjecting the metal to the action of a molten slag capable of dissolving the oxide, the slag containing boric acid, making it elastic while hot, but brittle when cold so as to permit easy removal thereof from the article.

1,704,410, Mar. 5, 1929, Method of Welding Rail Joints, Curt Stedefeld, of Heidelberg, Germany.

This patent describes a method of treating welded rail joints which have been locally overheated by electrical or thermit welding to restore the metal adjacent the joint to its proper texture and wearing qualities. The method comprises heating the welded rail joint above the critical temperature, quenching and reheating to a temperature below the upper critical temperature and cooling. The heating is preferably carried out by means of electrical heating means laid around the welded joint in a manner similar to open incandescent electric furnaces, quenching, by means of oil and water sprays, and reheating and cooling down in air.

1,704,733, Mar. 12, 1929, Alloy, Frank A. Fahrenwald, of Cleveland Heights, Ohio.

This patent describes a high melting point alloy consisting of aluminum 3 to 20 per cent and chromium 97 to 80 per cent which has a melting point of about 3500 degrees Fahr. and therefore cannot be produced by any of the direct melting processes available commercially at the present time. The alloy is produced by pouring molten aluminum and molten chromium together, which causes a violent exothermic reaction, producing a temperature above the melting point of the alloy permitting thorough intermingling. Fused magnesite has proven to be the most satisfactory refractory to use in the production of such an alloy.

1,701,976, Feb. 12, 1929, Method of Conditioning Articles of Manganese Steel, George R. Hanks, of High Bridge, New Jersey, Assignor to Taylor-Wharton Iron and Steel Company, of High Bridge, New Jersey, a corporation of New Jersey.

This patent describes a method of conditioning manganese steel articles to give them uniform wear and obviate the wasteful self-conditioning properties of the articles in service, which comprises exposing the manganese steel articles, containing 10 to 15 per cent manganese, to selectively gauged shocks which are applied to the article while cold and before it is put into service. Further refining of the metal may include the preparation of a wear diagram of a corresponding worn article and cold working the article in accordance with the diagram to produce the desired result.

THE ENGINEERING INDEX

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In the preparation of the Engineering Index by the staff of the American Society of Mechanical Engineers some 1700 domestic and foreign technical publications received by the Engineering Societies Library (New York) are regularly searched for articles giving the results of the world's most recent engineering and scientific research, thought, and experience. From this wealth of material the A. S. S. T. is supplied with this selective index to those articles which deal particularly with steel treating and related subjects.

AIRPLANE MATERIALS

DURALUMIN SHAPES. Extruded Duralumin in Aircraft, J. F. Hardecker. *Airway Age*, vol. 10, no. 3, Mar. 1929, pp. 270-274, 8 figs.

Detailed information concerning extruded duralumin shapes which so simplifies fabrication of aircraft as to make it ideally suitable for quantity production; present construction materials and general properties reviewed; collection of Aluminum Company of America shapes used in float construction; simplicity of design and ease of fabrication possible with extruded shapes in fuselage; ease of inspection; table of shapes obtainable.

STAINLESS STEEL. Stainless Steel and Iron, W. Hackett, Jr. *Roy. Aeronautical Soc. J. (Lond.)*, vol. 33, no. 219, Mar. 1929, pp. 235-238.

Manufacture of stainless steel and iron described; Austenitic hardened only by cold working; methods of making Staybrite class of steels; creep of this steel; tubes drawn; streamline sections; properties and manufacture of stainless iron; welding tests on chrome-molybdenum tubing.

TUBING. Steel Tubes, Tube Manipulation and Tubular Structures for Aircraft, W. W. Hackett. *Royal Aeronautical Soc. J. (Lond.)*, vol. 33, no. 219, Mar. 1929, pp. 226-234.

Manufacture of steel tubing for airplanes is outlined; pilgering process; two methods of cold drawing; experimenting to overcome difficulty in drawing lighter-gage tubing; results of tests of chrome-molybdenum tubing show ultimate strength after welding invariably as high as original strength; chrome-nickel steel tubes; production of section tubes.

TUBING. Reynolds Tubing for Aircraft. *Aeroplane (Lond.)*, vol. 36, no. 4, Jan. 23, 1929, pp. 130, 132 and 134, 3 figs.

History of Reynolds Tube Co., Hay Hall Works, Tyseley, and description of their products; manufacture of solid-drawn nickel-chrome tubes; use in base member of longitudinal girders of R 101 airship; manufacture of manganese-steel tubing.

ALLOY STEEL

CORROSION TESTS. Resistance of Certain

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Steels to Chemical Influences in Relation to Carbon, Nickel, and Chromium Content (Ueber die Widerstandsfähigkeit einiger Stähle gegenüber chemischen Einflüssen in Abhängigkeit vom Kohlenstoff, Nickel und Chrom-Gehalt), F. Schmitz. *Zeit. fuer Metallkunde (Berlin)*, vol. 21, no. 2, Feb. 1929, pp. 64-65.

Results of corrosion tests show that carbon content has protective influence when steels are exposed to supply water, seawater, sulphurous acids, diluted and concentrated hydrochloric acids, or oxidizing gases; with oxidizing agents, chromium is only protective medium; with non-oxidizing solutions, nickel is the constituent which increases resistance of steel.

PROPERTIES. Welding Facts and Figures, D. Richardson and E. W. Birch. *Welding J. (Lond.)*, vol. 26, nos. 304 and 305, Jan. and Feb. 1929, pp. 6-9 and 38-40.

Jan.: Characteristics of alloy and special steels are discussed; theory of ternary steels and their structures; special elements which modify position of critical points and temperatures required for annealing and hardening. Feb.: Properties and methods of welding, hot working, and pickling are described; particulars of series of alloys made by Central Alloy Steel Corporation of America.

CUTTING QUALITIES. Cutting Qualities of an Alloy Steel as Influenced by its Heat Treatment, O. W. Boston and M. N. Landis. *Am. Soc. Steel Treating—Trans.*, vol. 15, no. 3, Mar. 1929, pp. 451-467 and (discussion) 467-473, 39 figs.

Estimating machinability rating of S.A.E. 6140 steel under various heat treatments; cutting rating as influenced by tool life and finish secured; torque and thrust of $\frac{3}{4}$ -in. drill as measured on drill dynamometer; time of $\frac{1}{4}$ -in. drill to penetrate $\frac{1}{4}$ in.; pure annealing does not give best machining qualities; steels cut best when spheroidizing is greatest.

MACHINING. Machining Qualities of Alloy Steels, H. Mayersberg. *Mech. World (Manchester)*, vol. 85, no. 2197 Feb. 8, 1929, p. 122.

Results of tests comparing machining qualities of six specimens of alloy steel; determination of life of tool from relationship between

speed of cut and volume cut away differs when machining steels of equal tensile strength but of different composition. Translated from *Werkzeug*.

ALLOYS

ANTI-CORROSIVE. Some New Developments in Acid-resistant Alloys, B. E. Field. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 191, Mar. 1929, 12 pp., 11 figs.

Paper describes part of investigation work on binary and ternary nickel alloys; nickel-molybdenum alloys have been found to possess resistance to hydrochloric acid, and fairly complete series containing molybdenum up to eutectic 49 per cent was studied; data on physical properties of nickel-molybdenum iron and nickel-silicon-copper-aluminum alloys.

EUTECTIC. Special Properties of Eutectics and Eutectoid Alloys in Binary Metallic Systems, P. Saldau. *Inst. of Metals—Advance Paper*, (Lond.), no. 487, for mtg., Mar. 13-14, 1929, 21 pp., 21 figs.

Hardness and electrical resistance of number of eutectic alloys studied, and it is shown that eutectic occupies special and abnormal position on property-composition curve, even in drastically annealed alloys; for coalescence to occur in eutectic alloys, excess of one of phases is necessary; polymorphic changes in some of constituent metals of system have been studied.

EUTECTIC — INTERCRYSTALLINE COHESION. Work-Softening and a Theory of Intercrystalline Cohesion, F. Hargreaves and R. J. Hills. *Inst. of Metals—Advance Paper* (Lond.), no. 488, for mtg., Mar. 13-14, 1929, 27 pp., 12 figs.

Conditions necessary for occurrence of work softening are: (1) presence of more than one phase; (2) both constituents must have property of undergoing spontaneous annealing after working at air temperature; theory of intercrystalline cohesion is outlined, which postulates existence of transition zone between two orientations; conditions respecting effect of stress and recovery; boundaries between different phases; cause of creep is attributed essentially to boundary action.

ALUMINUM ALLOYS

AGE HARDENING. The Age-Hardening of Some Aluminum Alloys, M. L. V. Gayler and G. D. Preston. *Inst. of Metals—Advance Paper* (Lond.), no. 489, for mtg., Mar. 13-14, 1929, 43 pp., 22 figs.

Physical properties of five typical aluminum alloys containing copper, magnesium silicide, or both, have been examined under similar conditions of heat-treatment; Brinell hardness, tensile strength density, and electric conductivity; changes in crystals as determined by X-ray analysis; precipitation from solid solution entails two processes which are considered.

RESEARCH. Recent Research of Technical Aluminum Alloys (Neuere Untersuchungen an verguethbaren Al-Legierungen), W. Fraenkel and L. Marz. *Zeit. fuer Metallkunde* (Berlin), vol. 21, no. 1, Jan. 1929, pp. 2-5 and (discussion) 5-6, 12 figs.

Comparative investigations were carried out on five different alloys to determine refining effects at room temperature, at 50, 100, and 150 deg. Cent., and at so-called cooking temperature, by measurements of Brinell hardness, tensile strength, and electric conductivity; re-

sults are discussed in light of prevailing refining theories.

RESEARCH. Equilibrium Relations in Aluminum-magnesium Alloys of High Purity, E. H. Dix, Jr. and F. Keller. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 187, Mar. 1929, 17 pp., 13 figs.

Report of investigation of equilibrium relations in aluminum rich alloys made from high purity aluminum manufactured by Aluminum Company of America; supplements four earlier papers.

WELDING. Welding Aluminum and Its Alloys, W. M. Dunlap. *Aviation*, vol. 26, no. 11, Mar. 16, 1929, (Aeronautical Eng. Sec.) pp. 40 and 45-51, 13 figs.

Information regarding fusion welding aluminum and its alloys is given; selection of tip size important; most effective method of removing oxide film; choice of welding metal; working speed greater than with steel; progressive tack welding necessary; flux should be used for castings.

ALUMINUM CASTINGS

WELDING. Repair of Aluminum Automobile Parts by Soldering and Welding (Grundsaetzliches ueber das Ausbessern von Aluminium-Motorfahrzeugteilen durch Loeten und Schweiessen), H. Reininger. *Motorwagen* (Berlin), vol. 32, nos. 6 and 7, Feb. 28 and Mar. 10, 1929, pp. 111-118 and 145-149, 19 figs.

Definition of terms, soldering and welding, with regard to special requirements of aluminum and its alloys; physical and chemical properties required of welded or soldered joints; suitable composition of soldering or welding media.

ALUMINUM CORROSION

Note on the Inhibition of the Corrosion of Aluminum by Soaps, H. V. Churchill. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 176, Feb. 1929, 6 pp.

Discussion of corrosion and prevention, with particular reference to collapsible tubes such as are used for packing shaving creams and similar commodities; tests indicated that effective inhibition of corrosion could be obtained by adding to shaving creams 0.2 per cent by weight of sodium silicate solution.

ALUMINUM WELDING

Forged Aluminum Welds. *Welding J.* (Lond.), vol. 26, no. 304, Jan. 1929, p. 12.

Process applied to heavy sheets, which consists in heating edges to be joined by means of oxyacetylene flame and hammering, and thus welding them together, while they are in semi-pasty condition, briefly described; disadvantages; exact temperature of tremendous importance; fusion welding of aluminum. From *Revue de la Soudure Autogene*.

BOILER PLATES

TEMPERATURE EFFECT. Elastic limits of Steel at Elevated Temperatures (Ueber die Streckgrenze von Stahl bei hoeheren Temperaturen), F. Koerber. *Stahl und Eisen* (Duesseldorf), vol. 49, no. 9, Feb. 28, 1929, pp. 273-277.

Stresses due to higher boiler temperatures are discussed and importance of research is emphasized; relation of temperature to elastic limit of steel; results applied to design of

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High Purity,
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BRASS

HEAT TREATMENT. Some Observations in Heat Treatment of Muntz Metal, L. R. Van Wert. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 180, Feb. 1929, 10 pp., 15 figs.

Notes on cleavage structure developed under certain conditions, and on abnormal grain growth, in alloy of 60 per cent copper and 40 per cent zinc; preliminary survey only, proper-ty noted by observations made during investigation of solubility relations.

METALLURGY. Brass and Special Brasses (Messing und Sondermessing), W. Wunder. *F. D. L.-Zeit. (Berlin)*, vol. 73, no. 5, Feb. 2, 1929, pp. 165-168, 13 figs.

Old and new methods of making zinc-copper alloys, phase-rule diagrams and texture; elimination of initial strains; recrystallization phenomena; making of special brasses by adding aluminum, lead, tin, or other metals.

BRIDGES, WROUGHT IRON

WELDING. Strengthening of Echuca Bridge by Electric Welding, W. D. Chapman. *Instn. Engrs. Australia—Jl. (Sydney)*, vol. 1, no. 1, Jan. 1929, pp. 9-18, 10 figs.

Strengthening and widening of combined wrought-iron plate-girder bridge over Murray River constructed in 1876-1878; total length 1452 ft., maximum span 112 ft.; reasons for and method of strengthening; tests of welding on old wrought iron; basis for design; repairs to cast-iron piers; widening roadway from 19 ft. 8 in. to 24 ft. 4 in.

CAST IRON

EUTECTIC. Eutectic Cast Iron, A. Mitin-ski. *Iron and Steel of Canada (Gardenvale, Que.)*, vol. 12, no. 2, Feb. 1929, pp. 55-56.

At no distant date hypereutectic cast iron will disappear; electric furnace, by elimin-ating ferric oxide and germs of primary gra-phite, while increasing fluidity of metal, will enable silicon and phosphorus contents to be reduced. Paper presented to Paris Foundry Congress.

HEAT TREATMENT. Heat Treatment and Properties of Cast Iron, P. Schoenmaker. *Heat Treating and Forging*, vol. 15, no. 2, Feb. 1929, pp. 170-173, 10 figs.

Effect of controlled initial melting tempera-tures and of subsequent heat treatments are studied; various elements affecting proper-ties; effects of treatments on hardness; physi-cal properties of hardened and tempered cast iron.

NICKEL. Practical Foundry Mixtures. *West. Machy. World*, vol. 20, no. 1, Jan. 1929, pp. 37-39.

Recommended nickel-iron mixtures for pres-sure castings, close-grained castings, heavy and light-section castings, liner and bushing castings, gear and pinion castings, production castings, and automobile-cylinder castings.

SPECIFICATIONS. Metallurgical Specifica-tions for High-class Cast Irons, H. J. Young. *Metallurgist (Supp. to Engineer, Lond.)*, Feb. 22, 1929, pp. 28-29.

In author's opinion engineer, through long familiarity with unreliability of cast iron, has become indifferent concerning it with results that he neither specifies material he requires

nor sees that he gets it; remedies are dis-cussed and recommendations made for obtain-ing test bar representative of casting; by adopting methods described engineer will get what he is paying for, iron he likes best, iron which never varies, etc.

CASTINGS

CLEANING. Cleaning Castings Hydraul-ically Saves \$6000 Annually, J. Prendergast. *Iron Trade Rev.*, vol. 84, no. 7, Feb. 14, 1929, pp. 456-459, 7 figs.

Method of Sullivan Machinery Co., Chicago, for cleaning castings is outlined; hydroblast does not do away with sand-blast altogether; on account of preliminary cleaning, work of sand-blast operator has been reduced to mini-mum; cost of installation, expense of opera-tion, and estimated yearly savings shown.

CHROMIUM-NICKEL STEEL

High Chromium and High Nickel Chromium Alloy Steels, S. J. Hewitt. *Can. Machy. (To-ronto)*, vol. 40, no. 3, Feb. 7, 1929, pp. 46 and 82.

Melting of these steels in basic lined elec-tric furnace is described; analysis of stainless steel and stainless iron; heat treatment.

The Stress-Strain Diagrams of a Heat Treated Nickel-Chrome Steel, A. Robertson and A. J. Newport. *Metallurgist (Supp. to Engineer, Lond.)*, Feb. 22, 1929, pp. 23-26, 4 figs.

Results of compression tests made on tubes 1¼-in. diam., 18 gage, supplied by Superin-tendent of Royal Air Force; approximate chemical composition was carbon 0.25, nickel 4.1, chromium 1.25.

New Chromium-Nickel Steel Gleams Like Polished Silver, E. C. Kreutzberg. *Iron Trade Rev.*, vol. 84, no. 11, Mar. 14, 1929, pp. 710-711 and 722, 5 figs.

Possibilities of chrome-nickel steel and its many applications are discussed; steel to be manufactured in United States by Ludlum Steel Co, Central Alloy Steel Corp, and Firth-Sterling Steel Co. under Krupp-patents under names of Strauss Metal, Dimondite, and Ni-rosta.

Soft Steel Resists Corrosion. *Iron Age*, vol. 123, no. 11, Mar. 14, 1929, p. 752, 1 fig.

Description of improved chromium-nickel steel marketed by three American companies under Krupp "Nirosta" patents.

CORROSION. Resistance of Iron-nickel-chromium Alloys to Corrosion by Acids, N. B. Pilling and D. E. Ackerman. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 174, Feb. 1929, 33 pp., 16 figs.

Tests on 90 experimental melts covering portion of range containing 30 per cent chro-mium or less; technique of corrosion testing; hydrogen-discharging acids; sulphurous acid and mixtures thereof; effect of constitution and heat treatment; tabular data and dia-grams of results of tests.

CORROSION. Iron-Chromium-Nickel Al-loys, W. Guertler. *Metallurgist (Supp. to Engineer, Lond.)*, Feb. 22, 1929, pp. 30-31, 3 figs.

Results of author's experiments; alloys tested were melted in vacuum furnace from electrolytic iron, pure Kahlbaum nickel and electrothermic chromium; in corrosive media where formation of oxide skin is possible im-munity of these alloys is due to chromium content, while in non-oxidizing media nickel

is element which increases chemical resistance. Abstract translated from Zeit. fuer Metallkunde, 1928.

WELDING. Problems in Welding Chrome-Nickel, E. D. Flinterman. *Welding Engr.*, vol. 14, no. 2, Feb. 1929, pp. 41-44, 6 figs.

Alloys with high coefficient of expansion, low heat conductivity, and coarse, irregular grain present difficult welding problem; in welding carbonizing boxes, welds cracked on cooling; plates easily welded on edges but not in center; results of tests; carbon arc makes welds on Misco very much faster than gas, but they are not as good physically; welding rolled Misco. Paper read before Welding Conference at Purdue University.

COPPER ALLOYS

HEAT TREATMENT. Heat Treatment and Mechanical Properties of Some Copper Zinc and Copper-Tin Alloys Containing Nickel and Silicon, W. C. Ellis and E. E. Schumacker. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 188, Mar. 1929, 17 pp., 8 figs.

Mechanical properties can be varied over wide range by suitable heat treatment; these alloys may have possibilities in manufacture of high strength brass castings; hardened by heat treatment would permit forming operation on manufactured part to be performed on soft material.

COPPER-SILICON ALLOYS

CORROSION. Resistance of Copper-silicon-manganese Alloys to Corrosion by Acids, H. A. Bedworth. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 189, Mar. 1929, 14 pp., 16 figs.

Commercial development of this type of alloy is recent; discussion of research by various investigators; description of tests on hard-drawn and annealed wires, of varying composition, after alternate immersion in dilute hydrochloric and dilute sulphuric acids; relative corrosion determined by measuring loss in weight, tensile strength, and elongation; discussion of results.

CRYSTALS

ANALYSIS. Progress in Crystal Analysis. *Engineering (Lond.)*, vol. 127, no. 3293, Feb. 22, 1929, pp. 242, 1 fig.

Pure metals, like copper, are too soft for most purposes; X-ray investigations of alloys are generally made by Debye-Scherrer method; photographs reproduced show changes observed in X-ray spectrum as more and more zinc is added to copper. Abstract of address before Roy. Inst.

DIE CUTTING

A New Method of Diamond Die Cutting, M. A. Hall. *Wire*, vol. 4, no. 3, Mar. 1929, pp. 86-87 and 100-102, 2 figs.

Wire drill used to replace needle and dust process turns out more accurate sizes in one-third time; four-day shop-production records.

DIES, FORGING

HEAT TREATMENT. English and American Die Tool Steels, J. W. Urquhart. *Heat Treating and Forging*, vol. 15, no. 2, Feb. 1929, pp. 177-182, 1 fig.

Review of contrasting composition as well as hardening, tempering and general thermal treatments; divergencies in practice; constitu-

tion of some English nickel-chromium steels; air-hardening properties of English steels; ratio of air-hardening to water-quench hardening; influence of rate of cooling of nickel-chromium steels; best alloy steels for die making; molybdenum alloys; heating and cooling ranges of die steels; American cold heading dies.

DURALUMIN CORROSION

Correlation of Laboratory Corrosion Tests with Service: Weather-exposure Tests of Sheet Duralumin, H. S. Rawdon. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 173, Feb. 1929, 24 pp., 7 figs.

Report of tests of heat-treatable aluminum alloys containing copper, magnesium, silicon, and manganese; such alloys may become brittle in service without any marked surface indications; method of exposure tests, and laboratory tests are described; results and discussion of tests.

ELECTRIC FURNACES

A New Small Electric Furnace. *Demag News (Duisburg)*, vol. 3, no. 1, Jan. 1929, pp. 22-23, 4 figs.

Description of small electric furnace combining advantages of both radiation and direct-arc heating, which was evolved by Demag; inclination and longitudinal adjustment of electrodes; application in shop and metallurgical research work.

Electric Heat for Process Work, J. F. Baker. *Factory and Indus. Mgmt.*, vol. 17, no. 2, Feb. 1929, pp. 268-269, 3 figs.

Facts governing choice of furnace equipment; electric furnaces are usually operated with lower labor and supervisory costs because of automatic control of power input by time clocks and pyrometers and readiness-to-serve feature of electric current; maintenance must be given serious consideration.

Recent Developments in Electric Furnaces, D. F. Campbell. *Inst. of Metals—Advance Paper (Lond.)*, no. 482, for mtg., Mar. 13-14, 1929, 20 pp., 13 figs.

Improvements and modifications in melting practice; small and large induction and high-frequency furnaces; construction and performance of number of heat-treatment furnaces, including continuous furnace for annealing brass strip; large brass works is described with explanation of uses to which electricity has been applied; diagrams showing energy consumed and effect of special precautions used to improve power and load factor.

ANNEALING. Annealing in Electric Furnaces, I. N. Moseley. *Ry. Jt.*, vol. 35, no. 2, Feb. 1929, pp. 25-26, 1 fig.

Results obtained by Norfolk and Western Foundry at Roanoke, in annealing of steel castings in single-end car-type furnace, having door at one end and truck which moves in and out of interior.

HEAT TREATING. The Electric Furnace for Hardening Steel, E. L. Hill. *Elec. Engr. of Australia and New Zealand (Melbourne)*, vol. 5, no. 10, Jan. 15, 1929, pp. 353-358, 6 figs.

Hardness and wearing quality of steel depends upon quenching taking place at exact moment; pyrometrical observation is not sufficiently accurate to give consistent results; accurate gaging by observing magnetic quality; in Wild-Barfield furnace, steel is heated electrically and automatic measurement is

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English steels;
water-quench hard-
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steels for die
castings; heating and
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Corrosion Tests
of Tests of Sheet
Iron. *Am. Inst. Min.*
Met., no. 173, Feb.

Available aluminum
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urnace. *Demag*
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Electric furnace com-
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vol. 17, no.
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Electric Furnaces,
Metals—*Advance*
Met., Mar. 13,

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made of its magnetic quality by indicator which gives positive reading showing correct moment of quenching; other high-temperature furnaces used for hardening of alloy steels also described.

HIGH FREQUENCY. Melting Steel in the High Frequency Furnace, H. Neuhauss. *Foundry*, vol. 57, no. 5, Mar. 1, 1929, pp. 192-194 and 218, 6 figs.

Figures on power consumption for producing stainless steel; data on possibilities of this furnace in connection with a cupola melting all steel scrap as duplexing unit for steel foundries.

HIGH FREQUENCY. Melting Steel in the High Frequency Furnace, H. Neuhauss. *Foundry*, vol. 57, no. 4, Feb. 15, 1929, pp. 146-150, 9 figs.

Action of high frequency furnace of Ajax Electrothermic Corp., and its possibilities in steel production are described; violent stirring action of liquid bath which is due to pinch effect opens entirely new metallurgical possibilities; in colorless furnace; steel has finished its deoxidation completely before pouring; data on 240-lb. melt in 150-kw. furnace; data from stainless steel melt.

INDUCTION. The Metrovick Coreless Induction Furnace. *Iron and Coal Trades Rev. (Lond.)*, vol. 118, no. 3184, Mar. 8, 1929, pp. 362-363, 4 figs.

Notes on construction and operating costs of improved types of furnace developed by Metropolitan-Vickers Electrical Co.; steel furnaces of 500-lb. and 350-lb. capacity; furnace for brass and other non-ferrous metals is mentioned, but not specifically described; tabular data on performance and comparison of ingot analyses; operating cost, on basis of 550 tons steel per year, is about 5 pounds 7 shillings per ton.

INDUCTION. Coreless Induction Furnace. *Foundry Trade J. (Lond.)*, vol. 40, no. 653, Feb. 21, 1929, pp. 141-142 and 154, 5 figs.

Furnace of improved type developed by Metropolitan Vickers Electrical Co. is described; for 5-cwt., 500-cycle steel furnace, supply of power is provided by motor-generator set which consists of 160-kw. 500-cycle, 1000-volt generator directly coupled to 265-hp. 1500-r. p. m. slip-ring induction motor; advantages of induction furnaces; comparative costs.

MELTING. Selection of Electrical Equipment for Arc Furnaces Used in the Melting and Refining of Ferrous Metals, S. Arnold, 3rd. *Iron and Steel Engr.*, vol. 6, no. 2, Feb. 1929, pp. 75-78.

Selection of proper electric equipment for arc furnaces of Heroult type is discussed, dealing with correct transformer capacity and with proper voltage range and control, design of bus and cable structure, application of regulating and metering equipment, and switching equipment. Presented before Elec. Heating Conference.

METALLURGICAL. Heating Metals by Electricity, P. Hoho. *Elec. Rev. (Lond.)*, vol. 104, nos. 2671 and 2672, Feb. 1 and 8, 1929, pp. 185-187 and 299-331, 8 figs.

Principle and essential characteristics of special process adapted for welding, hardening, and other industrial operations are summarized; bath temperature and homogeneity; metallurgical applications; method of utilizing bath for forging or bending of iron; fu-

ture developments of process are considered.

RESISTANCE. Economic Considerations in Construction and Operation of Electric Resistance Furnaces (Wirtschaftliche Ueberlegungen bei Anschaffung und Betrieb elektrischer Widerstandsoefen), V. Paschke. *Archiv fuer das Eisenhuettenwesen (Duesseldorf)*, vol. 2, no. 8, Feb. 1929, pp. 487-494, 10 figs.

Term, resistance furnace, is defined; principles underlying heat economy, and calculations and considerations governing selection and operation of resistance furnaces are discussed, with special regard to operating costs, operating economies, etc.

RESISTANCE. An Improved Form of Electric Resistance Furnace. E. Rosenhain and W. E. Prytherch. *Inst. of Metals—Advance Paper (Lond.)*, no. 483, for mtg., Mar. 13-14, 1929, 5 pp., 2 figs.

Electric resistance furnace is described for which advantages are claimed in regard to higher available working temperatures (up to 1400 deg. Cent.), durability, and freedom from oxidation of carbon resistor; heating element consists of carbon or graphite pellets, or short rods placed end to end in refractory sheathing tube which fits easily over them; heating occurs by contact resistance.

RESISTANCE. Electric Resistance Furnaces in the Workshop (Elektrische Widerstandsofen im Werkstaettenbetriebe), H. Tamele. *Siemens-Zeit. (Berlin)*, vol. 9, no. 2, Feb. 1929, pp. 101-108, 2 figs.

Use of chrome-nickel heating elements in furnaces up to 1000 deg. Cent.; ceramic lining; muffle furnaces; hardening and melting furnaces of Siemens and Schuckert and their application.

TUNNEL. Theoretical Considerations in Electric Tunnel Kiln Design, J. Kelleher. *Am. Electrochem. Soc.—Advance Paper for Mtg.*, May 27-29, 1928, 6 pp., 2 figs.

Brief description of method followed in making design of electric tunnel furnace or electric tunnel kiln, as it is often called, from data on time-temperature cycle required by materials which are to be heat-treated in it; heat losses calculated.

FORGE SHOP PRACTICE

Forge Heating for Large Pieces, J. R. Miller. *Heat Treating and Forging*, vol. 15, no. 2, Feb. 1929, pp. 219-220, 2 figs.

Miscellaneous heavy products introduce complications not incident to heating of similar parts in mass production; fuel consumption figures are difficult to interpret; fuel economy; choice of fuels; pulverized coal admits of close regulation when proper arrangements have been made for its application.

FORGING MACHINES

Horizontal Forging Machines (Wagerecht-Schmiedemaschinen), H. Fey. *Stahl u. Eisen (Duesseldorf)*, vol. 49, no. 10, Mar. 7, 1929, pp. 315-324, 27 figs.

Field of application of forging machines and their advantages in production of forged parts; general description of forging process; details of different makes of machines.

FORGINGS—CLEANING

Cleaning Forgings in Shortened Time. *Iron Age*, vol. 123, no. 11, Mar. 14, 1929, p. 742, 1 fig.

Continuous process of cleaning forgings adopted at Cleveland Hardware Co., Cleveland, is described; pickling and tumbling combined in one barrel, followed by soda cleansing in second; operation facilitated by loading skip.

FURNACES, METALLURGICAL

DESIGN. Practical Industrial Furnace Design, M. H. Mawhinney. *Times Trade and Eng. Supp. (Lond.)*, vol. 23, no. 552, Feb. 2, 1929, p. 524.

Review of book published by Wiley, New York, purpose of which is to discuss practical methods for solving problems and difficulties most often met with in designing and operating industrial heating furnaces; it is restricted to metal industries, particularly iron and steel, and does not include melting furnaces.

PULVERIZED LIGNITE FIRED. Utilization of Rhenish Lignite in the Iron, Steel and Metal Industry (Rheinischer Braunkohlentstaub in der Eisen-Huetten- und Metallindustrie) H. M. Kaspers. *Archiv fuer Waerme-wirtschaft (Berlin)*, vol. 10, no. 2, Feb. 1929, pp. 57-61, 31 figs.

Use of pulverized lignite in heating, forging, annealing, and tempering furnaces is discussed. Bibliography.

GAS HEATING

INDUSTRIAL. What the South Metropolitan Gas Company is Doing to Stimulate the Industrial Load. *Gas World (Lond.)*, vol. 9 no. 2324, Feb. 16, 1929, pp. 17-20, 12 figs.

Developments in heat processes are discussed; heating and drying of tinplate and enameled goods in aircraft construction; air heating and ventilation in paper-making establishment; drying plant for treatment of enameled parts of motorcycles; heating steel car-wheel tires.

GASES—FLAME PROPAGATION

Flame Speeds and Their Calculation, W. Payman and R. V. Wheeler. *Fuel (Lond.)*, vol. 8, no. 1, Jan. 1929, pp. 4-8, 6 figs.

Observations on which law of flame speeds is based are summarized; object is to collate existing data concerning speed of flame with mixed inflammable gases, to show extent to which law is obeyed and to discuss exceptions to it.

GEARS AND GEARINGS—STRESSES

Visualizing the Stresses in Gearing, H. L. Bradford. *Am. Mach.* vol. 70, no. 10, Mar. 7, 1929, p. 393, 1 fig.

Details of simple polariscope built and used by Westinghouse Electric & Mfg. Co. for determining quickly and accurately tension stresses in teeth of gearing under load.

IMPACT TESTING

NOTCHED BAR. Effects of Notching (Die Kerbwirkung), A. Wewerka. *Maschinenbau (Berlin)*, vol. 8, no. 2, Jan. 17, 1929, pp. 33-37, 22 figs.

Local increase of stresses in material due to drilling, notching, and changing cross sectional area are discussed.

NOTCHED BAR. Notch Strength and Static Characteristics (Kerbzaehigkeit und statische Kennziffern), W. Kuntze. *Archiv fuer das Eisenhuettenwesen (Duesseldorf)*, vol. 2, no.

9, Mar. 1929 pp. 583-589 and (discussion) 590-593, 9 figs.

Influence of velocity of deformation on curve of true stresses; relation between notch resistance and strength and deformation properties of materials of same chemical composition; tests with different materials; influence of preliminary stretching on rupturing and notch resistance; material sensitive to blows.

INGOT MOLDS

Why Ingot Molds Have Short Life, J. H. Hruska. *Iron Age*, vol. 123, no. 8, Feb. 21, 1929, pp. 539-541, 6 figs.

Investigation revealing chemical, physical, and microscopical changes occurring in ingot mold walls during life of mold; large flakes of graphite detrimental; change in composition and surface hardness advocated; interesting study of changes on inner surface.

INGOT STEEL—TIN ADDITIONS

Influence of Tin on Quality, Especially Rolling Properties of Open-Hearth Ingot Steel (Der Einfluss des Zinns auf die Beschaffenheit, vor allem die Walzbarkeit von Siemens-Martin-Flussstahl), W. Keller. *Stahl und Eisen (Duesseldorf)*, vol. 49, no. 5, Jan. 31, 1929, pp. 138-139.

Notes on chemical determination of small contents of tin; investigations of plates with 0.25 to 0.99 per cent tin and varying carbon content; occurrence of cracks; cold bending tests; weldability and malleability tests; strength and elongation.

IRON

HEAT TREATMENT. Relation of Nitrogen to Blue Heat Phenomena in Iron and Dispersion Hardening in the System Iron-nitrogen, R. S. Dean, R. O. Day and J. L. Gregg. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 193, Mar. 1929, 10 pp., 12 figs.

Study of hardening by reheating after cold work, is made on three kinds of iron.

METALLOGRAPHY. The Gamma-alpha Transformation in Pure Iron, A. Sauveur and C. H. Chou. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 169, Feb. 1929, 18 pp., 14 figs.

Description of experiments conducted to confirm, if possible, accuracy of view that when gamma iron transforms into alpha iron on reaching A-3 point, each gamma grain does not change bodily into one or more alpha grains, but that alpha phase forms first at boundaries and along crystallographic planes of austenite grains; photomicrographic exhibits are submitted in evidence.

METEORIC. Neuman Bands in Meteoric Iron, S. W. J. Smith, A. A. Dee, and J. Young. *Metallurgist (Supp. to Engineer, Lond.)*, Feb. 22, 1929, pp. 31-32.

Clear picture is presented of manner in which authors consider lamellae to be produced by mechanical impulses which shear metal crystal uniformly in region of band in such a way as to produce a twin. Review of paper published in Roy. Soc.—Proc.

IRON ALLOYS

GAS DETERMINATION. Gases Extracted From Iron-Carbon Alloys by Vacuum Melting, N. A. Ziegler. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 168, Feb. 1929, 15 pp., 7 figs.

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Gases Extracted
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1929, 15 pp.,

Paper is continuation of work described by P. H. Brace and N. A. Ziegler in paper indexed in 1928 Eng. Index, under Electric Furnaces, High Vacuum; present work gives numerical data obtained as results of series of experiments with iron-carbon alloys.

HEAT TREATMENT. Influence of Heat Treatment under A-1 on Properties of Technical Iron (Der Einfluss einer Waermebehandlung unterhalb A-1 auf die Eigenschaften des technischen Eisens), W. Koester. *Archiv fuer das Eisenhuettenwesen (Duesseldorf)*, vol. 2, no. 8, Feb. 1929, pp. 503-522 including discussion, 34 figs.

Results of tests on improvement of iron with different low-carbon open-hearth and Thomas steels; influence of quenching under A-1 and annealing after quenching determination of tensile strength, elasticity, expansion, shrinkage, Brinell hardness, coefficient of bending, torsion, notch hardness etc.; change in structure; influence of carbon; relations to aging.

IRON AND STEEL

Discussion of Alloy Steels Marks Meeting of A. I. M. E. *Iron Trade Rev.*, vol. 84, no. 9, Feb. 28, 1929, pp. 621-623.

Review of New York meeting of Iron and Steel Division and Institute of Metals Division of American Institute of Mining and Metallurgical Engineers, with brief abstract of papers and discussion; two descriptions of blast furnace investigations by T. L. Joseph and C. E. Wood, and by S. P. Kinney and C. C. Furnas; other papers outlined.

SCRAP. The Use of Scrap in Gray Iron, Malleable, and Electric Steel Mixtures, E. K. Smith and F. B. Riggan. *Am. Foundrymen's Assn.—Preprint*, no. 29-3, for mtg. Apr. 8-11, 1929, pp. 51-70, 4 figs.

Many improvements in quality accompanied by carefully regulated use of scrap in mixtures; necessity for proper scrap sorting; classification; grades for gray iron and experimental mixtures; effect of borings, tin, zinc and burned material; scrap in malleable and electric iron and steel mixtures; desulphurization in relation to scrap use; effect of soda ash on all scrap mixtures.

IRON CORROSION

Corrosion of Iron in Sodium-Chloride Solution (Die Korrosion des Eisens in Chlornatrium-Loesung), W. van Wuelen Scholten. *Archiv fuer das Eisenhuettenwesen (Duesseldorf)*, vol. 2, no. 8, Feb. 1929, pp. 523-530, 10 figs.

Influence of surface conditions and oxygen admission on solubility of iron electrodes; tests with sodium-chloride solutions under influence of intermittent or continuous stirring; measurement of single potential with air admission and under hydrogen; graphic presentation of corrosion under different conditions.

IRON CASTINGS, CHILLED

Influence of Temperature of Molten Metal on Chill Castings (Ueber den Einfluss der Giess-temperatur beim Hartguss), F. Busse. *Gies-serei (Duesseldorf)*, vol. 16, no. 8, Feb. 22, 1929, pp. 169-179, 23 figs.

Results of research and author's own experience on influence of temperature of molten

metal on depth of hardness, transition from white to gray zone, occurrence of cracks and blowholes, etc.; microscopic analysis; relations between temperature of molten metal and crystallization; conclusions applied to foundry practice. Bibliography.

MAGNESIUM-ZINC ALLOYS

The System Magnesium-Zinc, W. Hume-Rothery and E. O. Rounsefell. *Inst. of Metals—Advance Paper (Lond.)*, no. 491, for mtg., Mar. 13-14, 1929, 20 pp., 12 figs.

Equilibrium diagram of system has been investigated in range 0 to 70 atomic per cent magnesium; structure of solid alloys and limits of solid solution in various phases.

MALLEABLE IRON CASTINGS

Malleable Cast Iron, C. H. Plant. *Iron and Steel Industry (Lond.)*, vol. 2, no. 5, Feb. 1929, pp. 151-152.

Defects which may occur in white-heart castings and mode of dealing with them; need for watching each stage of operation; defects arising in annealing process; occasional defects; distortion of castings; cracking during annealing; effect of some constituents on "peeling."

HEAT TREATMENT. The Heat Treatment of Malleable Cast Iron, H. A. Schwartz. *Fuels and Furnaces*, vol. 7, no. 2, Feb. 1929, pp. 187-191.

Maximum temperature in heat treating malleable castings should be as high as possible consistent with economical transmission of heat, maintenance of furnaces, deformation of castings under their own weight at high temperatures, and fusibility of any packing used to prevent such deformation.

MANGANESE STEEL

New Facts About Manganese Steel, J. H. Hall. *Iron Age*, vol. 123, no. 9, Feb. 28, 1929, pp. 600-601, 4 figs.

Nature of deformation lines in crystals of manganese steel, which was subject actively in Howe's mind during closing years of his life, is discussed; deformation lines contain martensite; discovery of heat treatment for grain refinement; new structure found in austenite. Abstract of Howe Memorial lecture presented before Am. Inst. Min. and Met. Engrs.

CASTING. Explains Manganese Steel Production in the Electric Furnace, J. Trantin, Jr. *Foundry*, vol. 57, no. 3, Feb. 1, 1929, pp. 128-131, 26 figs.

Effect of secondary heating, such as occurs in shrinking shells on rolls, welding and forging, on microstructure and physical properties is presented; data on drawing temperatures and micrographs to show changes occurring.

METALLOGRAPHY

Metallography Simplified for Practical Use in Shop, E. Preuss, G. Berndt, M. V. Schwartz. *Iron Trade Rev.*, vol. 84, no. 8, Feb. 21, 1929 pp. 520-522, 5 figs.

Structural constituents occurring in cooling and heating of iron with carbon content of 2.5 per cent are discussed; contents of individual fields of diagram of unstable equilibrium of iron; constitutional areas in stable iron-graphite diagram determined; cast iron containing finely distributed carbon will show

much greater strength than one with very large graphite crystals.

METALLURGY—RESEARCH

Metallurgical Research of the D. S. I. R. *Chem. Age (Lond.)*, vol. 20, no. 501, Feb. 2, 1929, (Met. Section) pp. 9-11.

Report of Department of Scientific and Industrial Research covering year ending July 31, 1928, containing following information: behavior of alloys at high temperatures; uses of alloys; research on minor metals; possible uses of beryllium, and alloys of beryllium; light alloys; mechanical properties and microstructures of electron alloy; fatigue of materials; electrodeposition; material for condenser tubes; work of Non-Ferrous Metals Research Assn.

METALS

GAS ABSORPTION. Absorption of Gases by Metals (Die Aufnahme von Gasen durch Metalle), A. Sieveris. *Zeit. fuer Metallkunde (Berlin)*, vol. 21, no. 2, Feb. 1928, pp. 37-44 and (discussion) 44-46, 15 figs.

Absorptive capacity of metals and alloys for oxygen, nitrogen, rare gases, sulphur dioxide, and hydrogen is set forth; supplement contains data on solubility of gases in metals.

GAS DETERMINATION. Investigation of Gases in Metals (Die Untersuchung der Gase in den Metallen), W. Hessenbruch. *Zeit. fuer Metallkunde (Berlin)*, vol. 21, no. 2, Feb. 1929, pp. 46-55 and (discussion) 55-57, 12 figs.

Significance of impurities, nature of affinity of gases, methods of gas determination, and apparatus employed are discussed; results of gas determination in copper, nickel, aluminum, zinc, and iron according to fusion in vacuum process are given.

GAS DETERMINATION. Gases in Metals. *Metallurgist (Supp. to Engineer, Lond.)*, Feb. 1929, pp. 17-18.

During recent years, increasing attention has been given to question of gases in metals, mainly from two points of view: one relates to analytical determination of gas content in given sample, while other relates to problem of eliminating gas from metal; while important work that is being done on removal of gases should be followed with interest, it is wise to inquire whether there are not circumstances in which certain gases may play useful or even necessary part.

GAS DETERMINATION. Technological Significance of Gases in Metals (Die technologische Bedeutung der Gase in Metallen) E. H. Schulz. *Zeit. fuer Metallkunde (Berlin)*, vol. 21, no. 1, Jan. 1929, pp. 7-11, 9 figs.

Nature of gas absorption by metals is discussed; peculiarities of gases as alloy constituents; blister formation by liberation of gases; technical importance of blisters and segregation phenomena caused by them; influence of oxygen on technical properties of metals, especially steel; absorption of iron in refining processes.

GAS OCCLUSIONS. Fusion of Metals in Vacuum (Recuit des métaux dans le vide), L. Guillet and A. Roux. *Revue de Metallurgie (Paris)*, vol. 26, no. 1, Jan. 1929, pp. 1-11, 9 figs.

Results of tempering and fusion in vacuum tests on certain metals carried out with purpose of determining nature and quantity of

gases which they contain and their influence on different properties of metals

PROPERTIES. The Relation Between the Properties of Engineering Materials and Their Ultimate Structures, G. W. Todd. *North-East Coast Instn. of Engrs. and Shipbldrs.—advance paper for meeting of Feb. 22, 1929*, 16 pp., 6 figs.

Atomistic doctrine of matter; relations between specific heats and coefficients of expansion; quantum theory leads to expressions from which specific heat of solid can be obtained in terms of its absolute temperature and characteristic frequencies of vibration of its atoms; evidence of X-ray analysis; electrical theory of crystal lattice; mechanism of deformation; observations on alloys.

REFLECTIVITY. Reflecting Power of Beryllium, Chromium and Several Other Metals, W. W. Coblenz and R. Stair. *U. S. Bur. of Standards—Jl. of Research*, vol. 2, no. 2, Feb. 1929, pp. 343-354, 7 figs.

Data on ultra-violet reflecting power of beryllium, chromium, cobalt, nickel, silver, speculum, stellite, and stainless steel; for chromium and beryllium observations extend into infra-red; beryllium has high reflectivity at 250 m- μ in ultra-violet and lower reflectivity with minimum at about 400 m- μ in visible spectrum; chromium has higher reflectivity than nickel in ultra-violet.

SPECTROGRAPHIC ANALYSIS. Use of Spectrographs in the Metal Industry (Anwendungen des Spektrographen in der Metallindustrie), F. Twyman, E. Honegger and D. M. Smith. *V. D. I.-Zeit. (Berlin)*, vol. 73, no. 6, Feb. 9, 1929, pp. 196-200, 14 figs.

Advantages of quantitative spectrographic analysis; use of ultra-violet section of spectrum; method particularly adapted to non-ferrous analysis, yet ferrous alloys can also be analyzed with aid of photometry; descriptions of modern spectrographs and spectroscopes.

VACUUM MELTING. Vacuum Melting, W. Rohn. *Metallurgist (Supp. to Engineer, Lond.)*, Feb. 22, 1929, pp. 26-27.

Facts and figures in regard to production of vacuum-melted metals in 1919-1928; important feature of vacuum process described is fact that casting into water-cooled copper ingot molds is also done under high vacuum; among materials produced by these methods, special alloys for use as thermocouples, both base metal and platinum, are important. Abstract translated from *Zeit. fuer Metallkunde*, Jan. 1929.

METALS CORROSION

Quantitative Measurement of Corrosion of Metals in Water and Salt Solutions, G. B. Bengough, J. M. Stuart and A. R. Lee. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 177, Feb. 1929, 20 pp., 10 figs.

Rate of corrosion is often rate of supply of oxygen to metal surface; three general methods used in estimating corrosion depend on measurement of change of weight, determination of metals in corrosion product and gas measurement; bulk of paper describes and discusses last method, as applied to corrosion of zinc.

Corrosion of Metals as Affected by Stress, Time, and Number of Cycles, D. J. McAdam, Jr. *Am. Inst. of Min. and Met. Engrs.—Tech. Pub.*, no. 175, Feb. 1929, 57 pp., 24 figs.

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Met. Engrs.—
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Citations of earlier papers on corrosion fatigue; tests now described were made on round $\frac{3}{4}$ -in. or 1-in. rods of iron, steel and alloy steels; paper discusses interrelationship of stress, time, and number of cycles in causing penetration of metals under corrosion; much space is given to discussion of constant-damage graphs.

Surface Films Protect Metals Against Corrosion, F. N. Speller. *Chem. and Met. Eng.*, vol. 36, no. 2, Feb. 1929, pp. 85-87.

Review of surface phenomena that modify corrosion; high-temperature oxidation; action of acid inhibitors; action of alkalis in solution; metals resistant to corrosion; superior resistance of high-chromium steels is due to surface film formed rather than to any great reduction in solution pressure of metal by chromium addition. Extracts from paper before Am. Assn. for Advancement of Science.

Some Aspects of Corrosion Fatigue, T. S. Fuller. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 172, Feb. 1929, 8 pp., 7 figs.

Pitting is admitted to be chief agent operating to reduce fatigue limits; tests undertaken to segregate effect of pitting from that of absorbed hydrogen; four uncorroded specimens, and others corroded by 10 per cent sulphuric acid, caustic soda, Schenectady tap water, and steam, respectively; some specimens were treated with protective coatings before subjected to corroding agent.

MONEL METAL CORROSION

Practical Application of Corrosion Tests; Resistance of Nickel and Monel Metal to Corrosion by Milk, R. J. McKay, O. B. Fraser and H. E. Searle. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 192, Mar. 1929, 47 pp., 11 figs.

Chief theme of paper is corrosion prevention; laboratory studies on action of milk on nickel, influence of various metals on dairy products, and influence of metals on human organism; field experiments at New York dairy and at plants producing milk products; conclusions are favorable, particularly as to nickel. Bibliography.

NICKEL CORROSION

INTERCRYSTALLINE. Nickel and Sulphur, W. Koester. *Metallurgist (Supp. to Engineer, Lond.)*, Feb. 22, 1929, p. 32, 1 fig.

It is shown that when nickel is heated in atmosphere containing sulphur dioxide, exposure of only one hour at temperature of 900 deg. Cent. is sufficient to produce marked brittleness in metal that was originally perfectly sound. Abstract translated from *Zeit. fuer Metallkunde*, Jan. 1929.

INTERCRYSTALLINE. Intercrystalline Corrosion of Nickel (Interkristalline Korrosion des Nickels), W. Koester. *Zeit. fuer Metallkunde (Berlin)*, vol. 21, no. 1, Jan. 1929, pp. 19-21, 9 figs.

Injurious effect of sulphurous gases on nickel is demonstrated; intercrystalline brittleness is due to accelerated progress of reaction along grain boundaries; microscopic analysis of change in structure; technical importance of problem is emphasized.

NICKEL METALLOGRAPHY

The Crystal Structure of Nickel, L. Mazza and A. G. Nasini. *London, Edinburgh and*

Dublin Philosophical Mag. and JI. of Sci. (Lond.), vol. 7, no. 42, Feb. 1929, pp. 301-311.

Pure cold-drawn nickel, after various thermal treatments, although sometimes showing peculiar recrystallization, always crystallizes in face-centered cubes; pure cold-drawn nickel subsequently annealed for long time does not show recrystallization structures, detectable by X-ray analysis, for annealing temperatures up to 940 deg. Cent.; quenching does not produce any change in dimensions of lattice of nickel.

NICKEL STEEL

IMPACT TESTING. Impact-Toughness of 3130 Steel Determined by Tests, T. H. Wickenden. *Automotive Industries*, vol. 60, no. 11, Mar. 16, 1929, p. 453, 2 figs.

Results of series of test on nine commercial heats of standard 3130 medium-carbon low-chrome nickel-steel to determine impact toughness and torsional properties; tests carried out in research laboratory of International Nickel Co. on materials from three different steel companies; 1500-1525 deg. Fahr. is found suitable temperature range for quenching.

PLATE MANUFACTURE. The Manufacture of Nickel-Steel Plate, C. McKnight. *Iron and Steel (A. S. M. E. Trans.)*, vol. 50, no. 32, Sept.-Dec. 1928, pp. 17-22 and (discussion) 22-23, 10 figs.

Manufacture, rolling, and inspection of steels, containing between 2 and 3 per cent of nickel, which are used in boiler construction, and particularly manufacture of fairly large plates of from $\frac{1}{4}$ to $1\frac{1}{2}$ in. in thickness, are discussed; physical properties of metal; details of its manufacture, beginning with ingot phase and proceeding then step by step through stripping and reheating, rolling, flattening, inspecting and shearing and finally testing.

NITRIDING

Surface Hardening by the Nitriding Process, H. W. McQuaid. *Am. Mach.*, vol. 70, no. 9, Feb. 28, 1929, pp. 360-362, 2 figs.

Operating practice as worked out by Timken-Detroit Axle Co., which has reduced time of nitriding below that of common practice is described; nitriding process relatively simple when compared with carburizing and hardening operations required to obtain good case-hardened work.

Practical Applications of the Nitriding Process, H. W. McQuaid. *Am. Mach.*, vol. 70, no. 10, Mar. 7, 1929, pp. 387-388.

Applications of process are discussed; nitriding has field for those parts that do not give satisfactory results when carburized, and in certain services which require rustless qualities; high cost is chief obstacle.

NONFERROUS METALS

GRINDING. Nonferrous Metals Present Interesting and Peculiar Grinding Problems. *Abrasive Industry*, vol. 10, no. 1, Jan. 1929, pp. 15-18, 8 figs.

Methods of grinding aluminum alloys, bronze, lead and babbitt alloys, brass, copper and bronze are described.

SPECIFICATIONS. Nonferrous Metal Specifications. *Foundry*, vol. 57, no. 3, Feb. 1, 1929, supp. plate no. 751.

Specifications for semi-plastic bronze and cast aluminum bronze are given.

NONFERROUS METAL INDUSTRY

GREAT BRITAIN. The Possibilities of Reviving Nonferrous Metallurgy in Great Britain, W. Cullen. *Metal Industry (Lond.)*, vol. 34, nos. 4, 5 and 6, Jan. 25, Feb. 1 and 8, 1929, pp. 97-100, 125-129, and 147-148.

Jan. 25: Decline in position of United Kingdom has taken place in nonferrous metal industry; present time most opportune for reorganization because of new metallurgical ideas, stabilized economic conditions, comparatively satisfactory fuel and power position, and proposed de-rating of industrial hereditaments. Feb. 1: Conclusions concerning gold, copper, lead. Feb. 8: Position of zinc, manganese, vanadium, chromium, molybdenum, and radium. Abstract of paper presented before Instn. Min. and Met.

REFRACTORY MATERIALS. Refractory Materials in the Nonferrous Metal Industry, A. B. Searle. *Metal Industry (Lond.)*, vol. 34, no. 2, Jan. 11, 1929, pp. 57-59.

In general sense, most nonferrous metals do not make any very serious demands on refractory materials, though there are exceptions such as lead and zinc and alloys containing them, which have highly corrosive action under some circumstances; author deals in detail with chief uses of refractories employed, and with future prospects of developments.

OPEN-HEARTH FURNACE

DESIGN. Possibilities of Improving the Heat Economy of Open-Hearth Furnaces (Möjligheter till förbättring av martinugnens varmekonomi), M. Tigerschild. *Jernkontorets Annaler (Stockholm)*, vol. 111, June 2, 1928, pp. 71-103, 23 figs.

History of open hearth furnaces; results obtained from three basic open-hearth furnaces in generation of gases when fired with wood or coal; details of closed insulated regenerators; improved burners; water-cooled gas and air intakes; utilization of heat of exhaust gases.

PRACTICE. Open-Hearth Problems Reviewed. *Iron Age*, vol. 123, no. 9, Feb. 28, 1929, pp. 603-606.

Review of open-hearth furnace sessions of Iron and Steel Division of American Institute of Mining and Metallurgical Engineers at New York meeting with brief abstracts of papers and round table discussion on physical chemistry of steel making; Gases Extracted from Iron-Carbon Alloys by Vacuum Melting, N. A. Ziegler; Unreduced Oxides in Pig Iron and Their Elimination, C. H. Herty, Jr., and J. M. Gaines, Jr.

BASIC PRACTICE. Basic Open-Hearth Furnace Yields, C. D. King. *Am. Inst. of Min. and Met. Engrs.—Tech. Pub.*, no. 186, Feb. 1929, 38 pp.

Discussion of yields, with reference to ingot yields obtained in process of converting pig iron, scrap, and ore to steel; in conversion, some scrap is produced; to ascertain cause of many possible losses, it is necessary occasionally to conduct carefully controlled heat tests; lower yield with higher ore and pig charges does not necessarily mean higher ingot cost in actual practice, since inexpensive iron in ore may offset disadvantage of lower yield.

BASIC PRACTICE. Basic Open-Hearth Furnace Yields, C. D. King. *Iron Age*, vol. 123, no. 9, Feb. 28, 1929, pp. 596-598, 1 fig.

Influence of various types of losses and how they should be calculated are discussed; duplex operation considered separately; example of method of calculating yields; where blast furnaces consume open-hearth slag, total losses are reduced by amounts used and their metallic contents. Abstracts of paper presented before Am. Inst. Min. and Met. Engrs.

RECUPERATORS. Influence of Dust Deposits on Efficiency of Checkerbrick Regenerators (Der Einfluss des Staubbags auf den Wirkungsgrad von Gitter-Wärmespeichern), A. Schack. *Stahl und Eisen (Duesseldorf)*, vol. 49, no. 5, Jan. 31, 1929, p. 140, 1 fig.

Discussion of damage due to dust and slags of poor conductivity on bricks of checkerwork regenerators, and how injurious effect can be calculated. Abstracted from Archiv fuer das Eisenhuettenwesen, Nov. 1928.

SULPHUR. Effect of Sulphur Content of Basic Open-Hearth Furnaces (En studie over svavlets forhallande vid basisk martinugnsdrift), A. Ahren. *Jernkontorets Annaler (Stockholm)*, vol. 84, no. 1-2, 1929, pp. 59-74, 8 figs.

Report from Stockholm Institute of Mining on qualitative and quantitative study made at Swedish iron works; sulphur in producer gas and in flue gases; ways of reducing sulphur content of product.

PIG IRON—PROPERTIES

Quality of Pig Iron and Castings as Affected by Blast Furnace Practice, A. L. Boegehold. *Am. Foundrymen's Assn.—Preprint*, no. 29-5, for mtg., Apr. 8-11, 1929, pp. 91-152, 23 figs.

Results of investigation conducted by General Motors Corp. given; physical characteristics of pig iron persist through cupola melting operation and are conferred upon cast iron; relation of cast iron properties to amount of moisture in blast; machinability improved by use of pig iron which has been completely reduced in blast furnace, and made more difficult by too rapid progress of iron through blast furnace; effect of quality of blast-furnace coke.

PIPE, CAST IRON

CENTRIFUGAL CASTING. The Centrifugal Casting of Iron Pipes, E. J. Fox and P. H. Wilson. *Iron and Steel Industry (Lond.)*, vol. 2, no. 5, Feb. 1929, pp. 147-150, 6 figs.

Survey of centrifugal casting of iron pipes; spinning of pipe; annealing operations; speed of rotation of mold; rate of flow of metal and rate of traverse; synchronizing operations; casting temperature; metal composition; production of chill; microstructure; metal composition of chill; microstructure; normalizing; mechanical tests; data on materials used. Abstract of paper read before Coordinating Societies at Birmingham.

Now Cast Pipe Centrifugally in Sand Molds. *Can. Machy. (Toronto)*, vol. 40, no. 6, Mar. 21, 1929, pp. 39-43, 10 figs.

Process of casting iron pipe centrifugally with use of refractory or sand mold, employed by Gartshore-Thompson Pipe and Foundry Co., Hamilton, is described; empty flasks moved to ramming station and rammed with sand, taken to casting machine and cast, removed

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RAILS

FLAW DETECTION. Electrical Apparatus
Locates Hidden Rail Flaws. *Ry. Elec. Engr.*
vol. 20, no. 2, Feb. 1929, p. 44, 1 fig.

Inspection car has been developed which
graphs hidden rail fissures and marks location
on track; based on law that flux surrounding
any conductor of uniform area will remain
unchanged unless there is defect or lack of
homogeneity in conductor.

PROPERTIES. Research on the Influence
of Rolling Temperature on Properties of Rails
(Untersuchungen ueber den Einfluss der Walz-
temperatur auf die Eigenschaften der Schien-
en), R. Stumper. *Stahl und Eisen* (Duessel-
dorf), vol. 49, no. 6, Feb. 7, 1929, pp. 177-
187, 29 figs.

Recent efforts toward improving quality of
rails by changing chemical composition are
discussed; possibilities of obtaining fine-
grained structure; influence of final rolling
temperature on strength, notch hardness, and
structure of rail steel No. 49 of German
National Railway was experimentally investi-
gated and results are given.

SILICON-MANGANESE STEEL. Silico-
Manganese Steel for Special Trackwork, H. A.
Richardson. *Elec. Ry. J.*, vol. 73, no. 6, Feb.
9, 1929, pp. 254-255, 1 fig.

Silico-manganese steel for special trackwork
is described; alleges ease and uniformity of
manufacture; hardness and toughness to re-
sist wear; ease of repair by welding.

STRESSES. Longitudinal Stresses in Rail-
road Tracks (Laengskraefte im Eisenbahn-
gleis), Gruenewaldt. *V. D. I.-Zeit. (Berlin)*,
vol. 73, no. 5, Feb. 2, 1929, pp. 157-161, 11
figs.

Report on laboratory and field experiments
at Karlsruhe Institute of Technology, on longi-
tudinal stresses in track rails caused by ther-
mal expansion; buckling of rails 45 m. long
due to axial pressure of 60 tons; instruments
for testing of rail joints, bolts, etc.; further
experiments planned.

SHEET MILLS

Sheet and Tube Tin Mill at East Chicago,
F. W. Manker. *Blast Furnace and Steel Plant*,
vol. 17, no. 2, Feb. 1929, pp. 291-292 and
304, 2 figs.

Plan of plant, heating equipment, and tin-
ning operation, described in detail; tin pots
fired by special burners, with temperature con-
trol.

SPECTRUM ANALYSIS

RESEARCH. Absorption Spectra of the Va-
pors of Tin, Silver and Manganese (Los es-
pectros de absorcion de los Vapores de Es-
tano Plata y Manganeso), R. G. Loyarte and
A. T. Williams. *Universidad Nacional de la
Plata (Buenos Aires)*, vol. 4, no. 86, Nov.
1928, pp. 483-499, 9 figs.

Results on tin and manganese agree with
those of Zumstein and of McLennan and col-
laborators; in absorption spectra of silver,
lines pertaining to ionized atom were ob-
served, which are to be taken up in later
work.

STEEL

AUTOMOBILE. Motor-Car Steels. *Mech.*

World (Manchester), vol. 85, no. 2196, Feb.
1, 1929, pp. 107-108.

Selection of both good and cheap steel for
automotive parts is discussed; steels used for
various parts of engine; two-bearing four-
throw cranks made of nickel chrome or nickel-
chrome molybdenum steel; steels for three-
bearing and five-bearing cranks; various steels
for connecting rods; gears of alloy case-hard-
ening steel or of oil hardening nickel-chrome
steel.

DEOXIDATION. The Physical Chemistry of
Steel-Making; Deoxidation with Silicon and
the Formation of Ferrous-Silicate Inclusions
in Steel, C. H. Herty, Jr. and G. R. Fitterer.
Min. and Met. Investigations—Bul. no. 36,
1928, 90 pp., 26 figs.

Inclusions in steel dealt with include only
ferrous silicates; system ferrous oxide-silica;
deoxidation and formation of ferrous-silicate
inclusions; function of silicon in basic open-
hearth process; segregation of silicon and sil-
icates in steel; equilibrium between silicon
and iron oxide.

TESTING. Recent Mechanical Tests of
Steel at Higher Temperatures (Neuere mecha-
nische Pruefungen von Stahl in der Waerme).
A. Pomp. *Jernkontorets Annaler (Stockholm)*,
vol. 111, June 2, 1928, pp. 44-66, 25 figs.

Review of recent experimental studies of
mechanical strength of steel, at temperatures
up to 1000 deg. cent., made by Mellanby and
Kerr, Oertel, French and Tucker, Koerber and
Pomp, Dickenson and others; details of special
apparatus used. (In German.)

TESTING—EVALUATION. Evaluation of
the Technical Worth of a Steel From Physical
Test Data, A. B. Kinzel. *Applied Mechanics*
(A.S.M.E. Trans.), vol. 50, no. 30, Sept.-Dec.
1928, pp. 13-16 and (discussion) 16-23, 1 fig.

Method of using various properties to help
predict relative ability of steels to withstand
service stresses is discussed; technical worth
may be combined with cost to give economic
worth; quantitative bend test as devised by
author; welded joints for pressure vessels;
steel for structural purposes; material for
deep stamping such as automobile fenders.

TESTING—HARDNESS. Relation between
Various Degrees of Hardness of Unhardened
Carbon Steel (Die Beziehung zwischen ver-
schiedenen Haerteziifern bei ungehaerteten
Kohlenstoffstaehlen), A. Wallichs and H.
Schallbroch. *Maschinenbau (Berlin)*, vol. 8,
no. 3, Feb. 7, 1929, pp. 69-74, 10 figs.

Steel containing from 0.1 to 1.0 per cent
of carbon was exposed to various hardening
tests, as result of which curve is plotted
showing ratio of Brinell hardness to new hard-
ness coefficient and corresponding equations
are derived. Bibliography.

RIMMED. Physical Chemistry of Rimmed
Steel, J. E. Carlin. *Blast Furnace and Steel
Plant*, vol. 17, no. 2, Feb. 1929, pp. 261-262.

Terms rimmed, open, and effervescent, are
applied to low carbon steels manufactured by
basic open-hearth and Bessemer processes to
which little deoxidation is applied with ex-
ception of manganese, either in furnace, ladle,
or molds; phenomena manifest in solidification
of ingots are explained in theory; practice
of producing rimming steel is outlined; physi-
cal chemistry of process.

STEEL ANALYSIS

INCLUSIONS. The Physical Chemistry of
Steel-Making; A Study of the Dickenson

Method for the Determination of Non-Metallic Inclusions in Steel, C. H. Herty, Jr., G. R. Fitterer and J. F. Eckel. *Min. and Met. Investigations—Bul.* no. 37, 1928, 25 pp., 5 figs.

Extraction methods proposed by previous workers; extraction with halogens, chlorine, bromine; iodine extraction and electrolytic extraction; Dickenson method; effect of Dickenson method on ferrous silicates; study of ferrous silicates in low-carbon steels.

STEEL CASTINGS

Symposium on Steel Castings, J. Jefferson. *Foundry Trade J.* (Lond.), vol. 40, no. 651, Feb. 7, 1929, pp. 105-106, 1 fig.

Replies to symposium previously published in Jan. 17 and 24, 1929, issues of Journal; difficult steel castings; X-ray situation; research at Woolwich is being concentrated into attempt to understand mechanism of hot tearing.

MANUFACTURE. How Steel Castings Are Made in Spain (Como se obtiene la fundición acerada en España), A. Lafont. *Ingeniería y Construcción (Madrid)*, vol. 7, no. 73, Jan. 1929, pp. 21-26.

Steel is prepared in open-hearth furnaces, converters, electric furnaces, crucibles, reverberatory furnaces, or cupolas; latter are most common and are used in artillery shops; ingredients of furnace charge; details of practice; test bars of material for projectiles. Extracts from lecture before Int. Foundry Congress, at Barcelona.

STEEL MANUFACTURE

RESEARCH. Unreduced Oxides in Pig Iron and Their Elimination in the Basic Open-Hearth Furnace, C. H. Herty, Jr. and J. M. Gaines, Jr. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 165, Feb. 1929, 20 pp., 9 figs.

Report of findings of sub-committee, with cooperation of U. S. Bureau of Mines Experiment Station at Pittsburgh, in investigation of reasons for occurrence of bad iron and study of methods for preventing its appearance; methods of testing; blast-furnace operation; nature of silicates; open-hearth heats; elimination of silicates in open hearth; effect of silicates on finished steel.

RIMMED STEEL. Manufacture of Thick-skinned Ingots of Rimming Steel, H. D. Hibbard. *Fuels and Furnaces*, vol. 7, no. 2, Feb. 1929, pp. 235-237.

Discussion of steel in mold, covering three kinds of gas holes that are present in rimming steel as it enters mold, their formation and effect on steel. (Continuation of serial.)

STEEL METALLOGRAPHY

Microscopical Studies of a Passive Layer in Carbon Steel and the Resulting Etch Structure (Mikroskopische Studien einer "passivierenden" Schicht am Kohlenstoffstahl und der resultierenden Aetzstruktur), C. Benedicks and P. Sederholm. *Zeit. fuer Physikalische Chemie (Leipzig)*, vol. 138, no. 1-2, Oct. 1928, pp. 123-134, 11 figs.

In studying etch figures produced on carbon tool steel by alcoholic nitric-acid solutions, unusual fissured effect was noticed which is attributed to existence of extremely thin passive layer; this is produced even with etch fluids containing only 0.1 per cent of

nitric acid; probable origin of this film is discussed.

The Constitution of Steel and Cast Iron, F. T. Sisco. *Am. Soc. Steel Treating—Trans.*, vol. 15, no. 3, Mar. 1929, pp. 503-515, 12 figs.

Structure of three transition constituents in heat-treated steel, martensite, troostite, and sorbite; under certain conditions it is relatively easy to identify martensite and troostite in their appearance and etching characteristics; sorbite usually can be differentiated from granular pearlite in same specimen, but it is difficult to detect sorbite in presence of troostite in tempered steels.

Steels, P. A. Riedel. *Sibley J. of Eng.*, vol. 43, no. 2, Feb. 1929, pp. 49-52.

Iron-carbon diagram is discussed; review of effect of addition of most common alloying elements.

STEEL PLATES

CORROSION TESTING. Laboratory Corrosion Tests of Mild Steel, With Special Reference to Ship Plate, H. S. Rawdon. *U. S. Bur. of Standards—J. of Research*, vol. 2, no. 2, Feb. 1929, pp. 431-440, 2 figs.

Series of corrosion tests of mild steels, including some Leviathan and other ship plate, was made by wet-and-dry and continuous-immersion methods in sea-salt solutions; steels varied in copper content from trace to over 0.60 per cent; corrosion rate in wet-and-dry test decreased as surface film was built up but was always much higher than that for simple immersion; laboratory test results have not confirmed claims made for Leviathan plate.

TUNGSTEN CARBIDE ALLOYS

The Important Discovery of Carbonyl. *Colo. School of Mines Mag.*, vol. 19, no. 2, Feb. 1929, pp. 16 and 20, 3 figs.

Note on alloy of tungsten carbide and cobalt, result of research in laboratories of General Electric Co., under direction of S. L. Hoyt; it is twice as hard as hardest steel that can be made, and is suitable for cutting tools in lathe work; can be used for machinery operations on glass, such as cutting screw threads in glass rod.

METALLOGRAPHY. A Metallographic Study of Tungsten Carbide Alloys, J. L. Gregg and C. W. Kuettner. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 184, Feb. 1929, 12 pp., 22 figs.

Results of investigation of structure of five alloys by means of microscopic and X-ray methods; no performance data are given and no inference is made as to inferiority of one alloy as against any other.

TUNGSTEN CARBIDE CUTTING TOOLS

Tungsten-Carbide Tool Efficiency, G. S. Brady. *Am. Mach.*, vol. 70, no. 9, Feb. 28, 1929, p. 346, 2 figs.

Description of endurance tests of tungsten carbide cutting tools run at Philadelphia Navy Yard; when operated under proper working conditions, and for purposes intended, they will cut hard and tough steels at higher speeds than have ever been attained by high-speed steels; when working at high speeds without overtaxing tools, they will stand up indefinitely without resharpening, thus making great savings in grinding and set-up time; economical operating speeds.

Recommended Practice Committee Releases

TENTATIVE GENERAL RECOMMENDATION FOR THE HEAT TREATMENT OF TOOL STEELS*

Purpose—Much of the general procedure for the heat treatment of one type of tool steel is applicable to others. These general instructions are to avoid repetitions in the Recommended Practices.

General—Often when correct temperatures are used, many hardening failures result from improper manipulation during heat treatment. The heat treatments given in the Recommended Practices apply specifically to certain types of steels, the basic compositions of which are given. This does not imply that such steels are the only suitable ones. These practices are primarily for the purpose of recommending heat treatments.

If more specific information is desired on any type of steel, it should be obtained from the supplier of the material.

Rate of Heating—The rate of heating for carbon tool steels is given in the Recommended Practices for the Heat Treatment of Plain Carbon Tool Steels.

The rate of heating for alloy tool steels is proportionally slower than for plain carbon steels as the alloying content increases.

Charging Furnace—Cold tools should be charged at comparatively low furnace temperature. Sudden changes in temperature should be avoided, except where steels such as high speed are changed from preheating furnaces to high heating furnaces purposely to obtain rapid heating. It is especially important to avoid sudden changes when reheating hardened steel, as breakage may result.

The steel should be placed in the furnace so as to expose the maximum surface. It is often advisable to place supports under the tool to raise it from the furnace bottom, thus allowing better heat circulation. An intricate tool should be supported in such a manner as to avoid warping.

Large Sizes—A range of temperature is usually given in recommendations for hardening heats. This does not imply that satisfactory results can be obtained on any tool if held anywhere within that range. Generally the larger pieces are heated to the high side of the range while small pieces are heated to the low side.

Uniform Heating of Tools—Cylindrical tools or intricate parts that have a tendency to heat non-uniformly should be frequently rotated.

*This is a Tentative Recommended Practice and will remain tentative for at least one year, until adopted by the Board of Directors and the Recommended Practice Committee of the A. S. S. T. This practice is not intended for a specification and should not be interpreted as such.

The membership of the Sub-committee on the Heat Treatment of Tool Steels is as follows: J. P. Gill, Chairman; J. A. Succop, W. H. Phillips, A. D. Beeken, Jr., Joseph Taylor, C. M. Johnson DuRay Smith, A. M. Cox, and Frank Garratt.

Criticisms of this Tentative Practice are solicited and should be directed to J. E. Donnellan, Secretary of the Committee, 7016 Euclid Ave., Cleveland, Ohio.

Holding at Heat—Care should be taken to hold the tool at temperature long enough to insure uniform heating throughout the section of the piece. Usually, steel of higher alloy contents will require more time, as noted in specific Recommended Practices. This gives a better solution of the constituents, but may cause some grain growth and surface decarburization, particularly at temperatures well above the critical range.

For the time of holding high speed steel at quenching heat, see the Recommended Practice covering this steel.

Furnace Atmosphere—Proper control of furnace gases is important. As far as possible a reducing atmosphere should be maintained at all times. Flames should not strike the steel.

Effect on Scale—If tool steel is heated above a low red heat while in contact with scale, even though in a neutral or reducing atmosphere, it will be decarburized. Therefore, care should be taken to keep steel, furnace hearth, and containers as free from scale as possible.

Thermocouples—The thermocouple should be so placed that the flames do not strike it and so located as to indicate as nearly as possible the temperature of the tool.

It is generally better to insert the thermocouple through the end or side of the furnace rather than in the top. For specific instructions on pyrometry see the A. S. S. T. HANDBOOK.

COOLING

Quenching Medium—The quenching medium should vary with the kind of steel treated as well as the speed of cooling necessary for various types of tools. Sufficient bath volume should be provided to maintain the quenching medium at proper temperature for uniform results. The use of air as a means of agitation and cooling for liquid baths is not recommended.

Oils—Oils generally give best results when used between the temperatures of 75 and 125 degrees Fahr. Some oils crack or otherwise deteriorate faster than others; consequently, should be replaced as found necessary.

Water—Water should be held at a fairly constant temperature, usually between 70 to 110 degrees Fahr. Fresh tap water is often aerated and may produce soft spots, so that water which has been previously boiled, or has been used frequently, is recommended. A strong stream of water will produce better results and help to throw the scale, while a spray sometimes gives more uniform results.

Brine—Tools quenched in brine will more readily throw their scale, producing a cleaner surface of more uniform hardness.

Air—Certain types of tool steels require air cooling. When using an air blast, it should be applied through a properly designed device and care should be taken to avoid the presence of water in the air line. If tools are cooled naturally (without blast) they should be supported so as to allow uniform cooling.

Quenching—Tools should be quenched in such a manner that warping is at a minimum. When immersing tools avoid the formation of gas pockets by vigorous agitation or by jets. It is important that the cooling medium come in contact with all parts of the work to be hardened. Tools should usually

1929

be removed before reaching the temperature of the quenching bath. For specific instances see the Tool Steel Recommended Practice in the A. S. S. T. HANDBOOK.

TEMPERING

Strains—Tools, after removal from the quenching bath and before tempering, are always in a highly and non-uniformly strained condition and danger of cracking is most pronounced. Tools should not become cold before tempering.

Uniform Tempering—Satisfactory tempering results are obtained by heating slowly and uniformly in a freely circulating medium. If a liquid is used, the tools should be placed in a metal basket for immersion which prevents contact with the sides or bottom of the container.

Charging the Tempering Furnace—When charging tools for tempering, the heating medium should be at a low temperature and the tools still warm.

Rate of Heating—Tools should be brought to heat slowly to prevent rapid release of hardening strains and warpage. Better results are obtained by holding at a lower temperature for a longer time. Generally the length of time should not be less than one hour at temperature, but for specific steels reference should be made to the Tool Steel Recommended Practices.

Cooling from Tempering—Slow cooling from the tempering operation is recommended, since rapid cooling may induce strains in the steel.

Tempering by Color—Temper colors are the result of slight oxidation of the surface of steel when heated at low temperatures, and are dependent upon time as well as temperature. They are only indicative of the temperature of the surface and do not indicate that the steel has been heated uniformly throughout. Tempering by color is not conducive to uniformity. When necessity requires that tools be tempered by color they should be heated slowly as in other operations and the heat raised progressively to the point or color desired, after which further tempering is usually stopped by quenching or withdrawing from the heating medium. The quenching should be done in the least drastic manner, preferably in oil.

NORMALIZING

Cementite Segregates—Normalizing implies heating steel far enough above the critical range to carry all cementite into solution and when this is done, it is followed by air cooling; cementite segregates may thus be broken up and a more uniform distribution obtained. This operation is more important on pieces that have been forged and should not be necessary on any material that has been annealed.

Rate of Heating—Heating tools for normalizing should be done in a manner similar to that of hardening.

Correct soaking time is proportional to the size of the piece. Prolonged soaking will coarsen the grain, rendering subsequent refinement difficult.

Rate of Cooling—The material is cooled from the normalizing temperatures in still air.

ANNEALING

Purpose—Tool steel is annealed to soften it for machining, forming, and grain refinement.

Packing—When the pieces are small it is advisable to pack them in charcoal to prevent scaling, decarburization, and too rapid changes of temperature. Care must be taken to keep the steel from contact with the container, and to avoid the presence of scale.

Heating—Heat slowly and uniformly to the temperature desired (See also specific Recommended Practices).

Holding at Heat—Hold at the annealing temperature long enough for complete penetration of heat and readjustment of grain. The time will increase with the weight of the charge and the alloy content of the steel.

Cooling—Cool slowly, preferably in the furnace, or in mica or other good heat insulating material. In general, the slower the cooling, particularly through the critical range, the softer the steel. As the alloy content of the steel increases the slower the steel must be cooled.

Strain Removal—Heating is sometimes carried out at a temperature below the critical range for purposes of strain removal. This operation is beneficial as a preparatory treatment for hardening tools on which considerable machining has been done. This treatment should be performed after the rough machining operations, but before heating for quenching.

Warping—The amount of warping on hardening is dependent on the shape of the tool, the kind of steel, the conditions of heating, and the severity of the quench. In general, water hardening steels warp more than oil hardening, and long, thin tools more than short, heavy ones.

Some causes of undue warpage are improper tool design, the use of the wrong type of steel, non-uniform or too rapid heating, improper support of the steel while heating, heavy machining, cold working strains, insufficient removal of surface, improper manner of quenching, non-uniform quenching, and non-uniform or too rapid tempering.

Soft Spots—Common causes of soft spots are decarburization, improper heating, quenching or bath agitation, gas pockets, tong contact, adhering scale, insufficient removal of surface, or defective furnace bottoms.

Straightening—When necessary to straighten, the operation should be performed when quenching on the descending heat. The tool may change somewhat in the tempering operation, but the peening required will not be nearly as much as if the tools are straightened on the quenching heat. A continuous press should be available with an adjustable control and knife edge rests, so that if one load does not satisfactorily straighten the tool another load can immediately be applied. For straightening on the descending heat, the tools should be withdrawn from the bath at a temperature from 500 to 600 degrees Fahr., which is just below the point where the oil ceases to flash, or in the case of water quenched tools, just where the water steams or dries off the tools immediately.

CONSTITUTION OF IRON-NICKEL ALLOYS

BY PAUL D. MERICA*

The structure and equilibrium of the binary iron-nickel alloys have engaged the attention and interest of metallographers from the earliest days of the science when Osmond¹ presented the first equilibrium diagram of this series. Exhibiting a marked case of temperature hysteresis of transformation change in the alloys containing up to 34 per cent nickel, and a curious anomaly in magnetic and elastic behavior of the alloys containing between 30 and 78 per cent nickel, it is not strange that this series should have been the subject of so much study and discussion through the intervening years. Even today there are many questions regarding the iron-nickel equilibrium that are far from being solved or clearly understood.

The diagram reproduced in Fig. 1 is a composite based upon the work of most of those cited in the references, but chiefly: Hanson and Hanson²⁷ (transformations), Hanson and Freeman²⁸ (liquidus and delta region); and Honda and Miura³² (irreversible transformations).

The equilibrium above 900 degrees Cent. is clear. The temperature interval of freezing is not known with accuracy, but it is small. The freezing point displays a flat minimum at above 65 per cent nickel.

In the solid state the alloys exist in three solid solution phases as follows:

delta—body-centered cubic lattice; parameter similar to that of alpha; exists within the field a c b.

gamma—face-centered cubic lattice; parameter varies from that of nickel (3.54×10^{-8} cm) to 3.60×10^{-8} cm for 27 per cent nickel-iron; exists at all temperatures beyond 34.4 per cent nickel, at temperatures above e f for lower nickel contents and occasionally within area c e f h i.

alpha—body-centered cubic lattice; parameter varies from that of iron (2.86×10^{-8} cm) to 2.875×10^{-8} for 32 per cent nickel-iron; exists below e i and occasionally within area of c e f h i.

The delta and alpha phases are similar in all respects and should be regarded as the same phase with separated temperature ranges of stability.

Below 34.4 per cent nickel the γ phase, upon cooling, suffers a transformation to the α phase, and because of the marked temperature lag between cooling and heating this has been called the "irreversible" transformation, and the alloys, the "irreversible" steels. Due to the marked temperature hysteresis of this transformation the true or equilibrium temperature position is not known. It is indicated on the diagram by the two temperature ranges actually observed on slow cooling and on slow heating.

The opinion is that these two temperature ranges (e f g and e h i) represent in reality one range of heterogeneous equilibrium, which lies somewhere between the two and which is the equilibrium range of the transformation and of the stable existence of both the γ and the α phases. That there is such an equilibrium temperature range of duplex phase structure is evident

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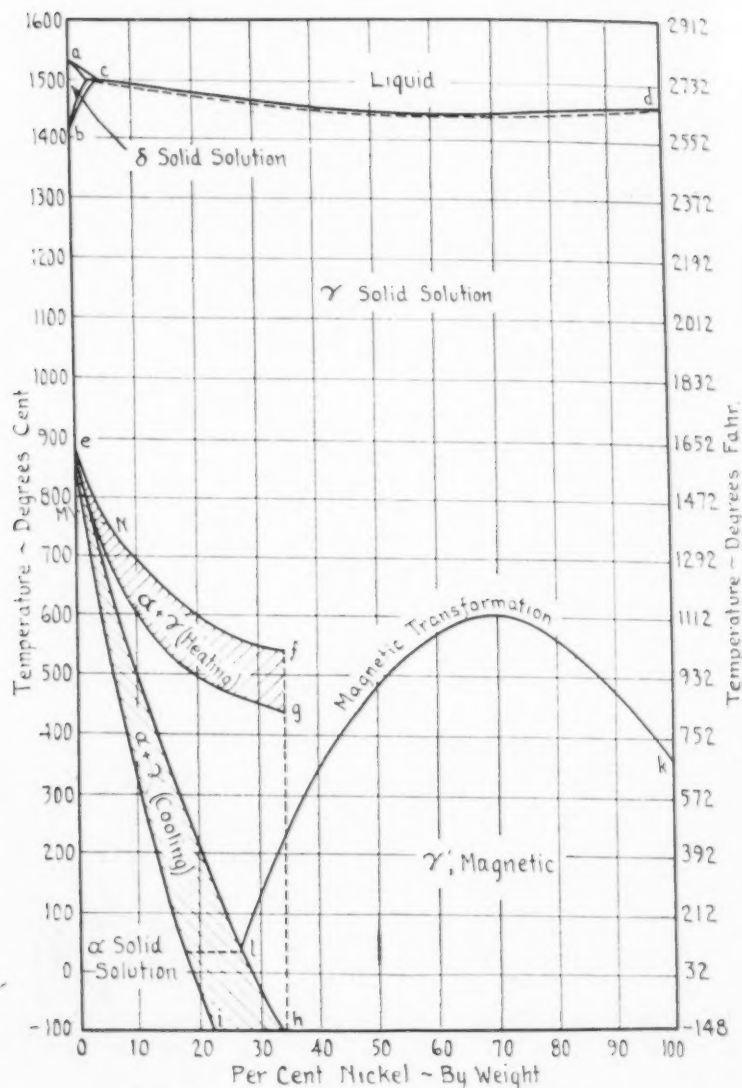


Fig. 1—Iron Nickel Equilibrium Diagram.

from a consideration of meteor structure. Below 780 degrees Cent. the two phases γ and α are distinguished by the fact that the former is para, while the latter is ferro-magnetic. The magnetic method has been widely used as a means of identifying the two. The line MN represents the temperature of the A_2 magnetic transformation, which is known only approximately.

Beyond 34.4 per cent nickel the alloys suffer a magnetic transformation shown on the diagram by the line l k, but it is the present opinion that this does not correspond to a phase transformation. The chief evidence for this point of view is that of X-ray analysis which has demonstrated that there is no change in lattice type in passing through the transformation l k, and no discontinuous change in lattice parameter. The evidence therefore seems to support the view that whereas the "irreversible" transformation is a true phase

transformation, definite and clear, the "reversible" one is associated with changes within the atom or perhaps within a small group of atoms,²⁵ which does not affect primarily the lattice organization and is hence not a true phase transformation.

This transformation is thus similar to that of iron at A_2 and to that of nickel. In consequence of their reversible transformation, these alloys have been called the "reversible" nickel steels or ferro-nickels.

The reversible transformation also proceeds in the alloys of lower nickel content insofar as they contain the γ phase as indicated on the diagram. Alloys having between 26 and 34 per cent nickel may therefore undergo either the "reversible" or the "irreversible" or both transformations, depending on their past thermal history.

Between 30 and 78 per cent nickel the magnetic transformation is the origin of the so-called "anomaly" of the "reversible" ferro-nickels. Associated with it are marked but apparently quite continuous changes in all physical properties, particularly density (dilatation or expansion) and elasticity. At 36 per cent nickel there is such a pronounced arrest in the thermal expansion below the magnetic transformation that industrial use has been widely made of the alloy, under the name Invar^{2,4}.

The simple conception outlined above of the nickel-iron equilibrium below 900 degrees Cent. is not shared by all authorities. The principal point of dispute is the nature of the "reversible" transformation.

Benedicks¹¹ believes that there is an actual phase change associated with the reversible transformation between 30 and 78 per cent nickel, which explains the dilatation and contraction observed on ageing the alloys showing the dilatation anomaly. Those who share this belief are inclined to suspect the existence of a eutectoid transformation: $\gamma \rightarrow \alpha$ plus magnetic γ' , which has been placed variously at 0 degrees Cent. and 345 degrees Cent., although no direct evidence of this transformation is available. In some iron-nickel meteors, structures have been observed strongly suggestive of eutectoid structure, but this is not necessarily adequate evidence of eutectoid transformation. Chevenard²² believes that the reversible anomaly is associated with a molecular (but not a phase) transformation involving the formation and dissociation of the compound Fe_2Ni (34.4 per cent nickel). He has pointed out the significance of the fact that it is at this composition that the irreversible transformation ends.

It is evident from this discussion that the irreversible alloys are subject to heat treatment in the same sense and in much the same manner as steel. The segregate of α phase resulting from its separation from γ resembles the structure and the mode of formation of martensite. These alloys are often called martensitic nickel steels, since they are fairly hard even after air or slow cooling.

The reversible alloys are not affected in the usual sense by heat treatment and are only moderately hard under all conditions.

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News of the Society

MINUTES OF MEETING OF BOARD OF DIRECTORS

BENJAMIN FRANKLIN HOTEL, PHILADELPHIA, OCTOBER 11, 1928

Present

F. G. HUGHES	W. H. PHILLIPS
ZAY JEFFRIES	W. H. EISENMAN
J. M. WATSON	F. T. SISCO—Nominee elect
J. F. HARPER	A. H. D'ARCAMBAL—Nominee elect
J. H. NEAD	R. G. GUTHRIE—Nominee elect
L. D. HAWKRIDGE	

Absent

T. E. BARKER

The meeting was called to order at 10:30 p. m. by President Hughes and several pending matters of importance were given consideration.

Upon motion properly made, seconded and unanimously accepted, it was decided that the president, vice-president, treasurer and secretary should represent the American Society for Steel Treating at the Semi-Annual Meeting of the Society to be held during the Western Metal Congress at Los Angeles, January 14 to 18, 1929.

Respectfully submitted,

W. H. EISENMAN, *Secretary*.

MINUTES OF MEETING OF BOARD OF DIRECTORS

SOCIETY HEADQUARTERS, CLEVELAND, FRIDAY, FEBRUARY 15, 1929

Present

ZAY JEFFRIES	W. H. PHILLIPS
R. G. GUTHRIE	F. T. SISCO
J. M. WATSON	A. H. D'ARCAMBAL
T. E. BARKER	W. H. EISENMAN

Absent

F. G. HUGHES

Upon motion properly made, seconded and carried, the minutes of the previous meeting of the Board were read and approved.

Upon motion by Mr. Watson, seconded by Mr. Sisco and unanimously carried, the committee appointments previously made by President Jeffries and ratified by the Board by letter ballot were confirmed.

Upon motion properly made, seconded and unanimously carried, the Board expressed their deep regret at the death of S. W. Miller, who was a recent appointee on the Recommended Practice Committee. Upon motion by Mr. Barker, seconded by Mr. Watson and unanimously carried, the president and two members of the Board that he may appoint, were authorized to select

without further reference to the Board, a member for the Recommended Practice Committee to replace Mr. Miller.

The report of the Finance Committee was then presented by Chairman Watson and after consideration the following action was taken.

Upon motion by Mr. Watson, seconded by Mr. Sisco and unanimously carried, bad accounts, to the amount of \$339.46, were written off.

Upon motion by Mr. Watson, seconded by Mr. Barker and unanimously carried, inventory to the amount of \$8307.98, as recommended by the Finance Committee, was approved.

Upon motion by Mr. Watson, seconded by Mr. Guthrie and unanimously carried, the recommendation that the furniture and fixture item be written down to the value of \$500.00 was approved.

Upon motion by Mr. Watson, seconded by Mr. Sisco and unanimously carried, the Board approved the profit and loss statement for the 1928 Convention.

Upon motion by Mr. Watson, seconded by Mr. d'Arcambal and unanimously carried, the Board approved the trial balance sheet for 1928 as recommended by the Finance Committee, subject to such revisions as might be made in later actions of the Board.

Upon motion by Mr. Watson, seconded by Mr. Phillips and unanimously carried, the budget as submitted by the Finance Committee was approved with changes made necessary by actions of the Board. The budget is as follows:

Budget for the Year 1929

INCOME

Membership Dues	\$ 64,000.00	
Sustaining Exhibit Membership	6,000.00	
TRANSACTIONS Advertising	52,000.00	
TRANSACTIONS Subscriptions	2,000.00	
TRANSACTIONS Sales	1,000.00	
Reprints	1,000.00	
Bindery	1,000.00	
Book Account	3,500.00	
Books Published	6,500.00	
Data Sheets, Binders and Books	2,500.00	
Extension Division	10,000.00	
Interest Earned	7,500.00	
Interest Earned—H. M. Howe Medal Fund	212.50	
Discounts Earned	1,000.00	
Miscellaneous Items	500.00	
1929 Convention	100,000.00	
Western Metal Congress	40,000.00	\$298,712.50

EXPENSE

Apportionment of Dues to Chapters.....	\$ 27,200.00
Support of Chapters	500.00
TRANSACTIONS	49,650.00
Reprints	1,500.00
Bindery	1,500.00
Books—For Library	250.00
Purchases for Resale	3,000.00
Books Published	4,800.00
Data Sheets, Binders and Books	4,350.00
H. M. Howe Medal Fund Expense	600.00
E. D. Campbell Memorial Lecture	500.00
Extension Division	10,000.00
Semi-Annual Meeting and Western Metal Congress	35,000.00
National Committees	5,000.00
Director's Expense	2,500.00
President's Office	1,000.00
Treasurer's Office	7,200.00
Secretary's Office	18,300.00

General Expense	12,550.00	
Reserves	15,312.50	
1930 Convention	1,000.00	
Western States Metal and Machinery Exposition	1,000.00	
1929 Convention	96,000.00	\$298,712.50

Upon motion by Mr. Watson, seconded by Mr. Guthrie and unanimously carried, the recommendation of the Finance Committee was approved providing that the treasurer should complete arrangements with the Cleveland Trust Company for a safe keeping account whereby the bonds of the Society would be handled by the Cleveland Trust Company.

Upon motion by Mr. Phillips, seconded by Mr. d'Arcambal and unanimously carried, the recommendation of the Board that \$15,000.00 additional of the Society's funds should be invested in high grade bonds was approved and the Board further extended to the Finance Committee the privilege of purchasing high grade bonds or debentures with convertible privileges in case the Finance Committee would deem it advisable.

The secretary then read a report on the Western Metal Congress and the Western States Metal and Machinery Exposition.

The secretary then presented a report with reference to a future Western Metal Congress and Exposition, and upon motion by Mr. Sisco, seconded by Mr. Guthrie and unanimously carried, it was decided that the A. S. S. T. should sponsor another Western Metal Congress and Exposition in the West in 1931.

The secretary presented a progress report on the 1929 Cleveland Exposition and also a progress report on the National Metal Congress.

Consideration was then given to the meeting and convention activities for 1930. Upon motion by Mr. Sisco, seconded by Mr. Phillips and unanimously carried, Messrs. Barker, d'Arcambal and Eisenman were appointed as a committee, with power to act, in the selection of the time and place of the 1930 semi-annual meeting.

Upon motion by Mr. Sisco, supported by Mr. Watson and unanimously carried, Messrs. Guthrie, Barker, Hughes and Eisenman were appointed as a committee to investigate convention offers for 1930 and to make recommendation as to time and place to the Board for future action.

It was the consensus of opinion of the Board that the 1930 convention and exposition should be held in the central West.

The secretary presented a report on the engineering extension work for 1928 and plans for 1929.

Upon motion by Mr. Barker, supported by Mr. Watson and unanimously carried, the problem of arranging future extension work with Mr. Keller was left in the hands of the secretary with power to act.

Upon motion properly made, seconded and carried, Dr. Albert Sauveur was nominated as the fourth Campbell Memorial Lecturer, which confirmed the letter ballot to the directors by mail upon this subject. A communication was read from Dr. Sauveur accepting the nomination and the secretary was instructed to communicate the Board's pleasure to the Doctor for his acceptance of the appointment.

A progress report on the HANDBOOK was presented. Upon motion by Mr. d'Arcambal, supported by Mr. Watson and carried, headquarters was author-

ized to proceed with the publication of a revised copy of the HANDBOOK to be available for distribution February 1, 1930.

Consideration was then given to correspondence in the National Office from the New York chapter and from the sponsors of the proposed Newark chapter, and the president and secretary were authorized to meet in New York with representatives of the two groups and come to some adjustment of the situation.

Dr. Jeffries presented to the Board a communication from Mr. Tour which contained a complaint against two of the data sheets at present in the HANDBOOK. Upon motion by Mr. Sisco, seconded by Mr. Guthrie and unanimously carried, the secretary was directed to notify the Recommended Practice Committee of the complaint against these two data sheets and to request the Committee to consider these two data sheets with reference to eliminating any possible inaccuracies or making such changes which would add to their improvement.

Upon motion by Mr. Watson, supported by Mr. Guthrie and unanimously carried, it was authorized that all retiring directors and officers of the A. S. S. T. should receive an officer's medal in recognition of their services. This is a renewal of the practice which was in effect for several years at the beginning of the Society's activities.

Upon motion by Mr. Barker, supported by Mr. Watson and unanimously carried, the secretary was instructed to continue past presidents as members of the Society without the payment of the \$10.00 dues.

Upon motion by Mr. Barker, seconded by Mr. Watson and unanimously carried, the salary of the secretary was increased \$2000.00 a year.

The meeting adjourned at 6:30 p. m.

Respectfully submitted,

W. H. EISENMAN, *Secretary*.

FINANCIAL STATEMENT OF THE AMERICAN SOCIETY FOR STEEL TREATING FOR THE YEAR 1928

The official report of Ernst and Ernst, certified public accountants, covering the results of their audit of the books of the society, is submitted herewith.

The official copy of this report is on file at the society offices and is open for the inspection of any interested members.

Ernst and Ernst, who made the audit, certify as follows:

"We have examined the books of account and record pertaining to the Assets and Liabilities of the AMERICAN SOCIETY FOR STEEL TREATING—CLEVELAND, as of the close of business December 31, 1928, and submit herewith our report. Our examination did not include a detailed audit of all the membership records, dues, sales invoices, etc., our work in this respect having been confined to test checks.

"Balance Sheet, setting forth the Assets and Liabilities of the Society as of the close of business, December 31, 1928, is included as a part of this report subject to the following comments:

"Cash on hand was verified by actual count during our examination and Cash on deposit by direct communication with the depository banks and

reconciliation of the reported amounts with the balances shown by the Society's books at December 31, 1928. All recorded Cash receipts for the year ended December 31, 1928, were traced by us directly into the bank deposits, as evidenced by bank statements on file, and all cancelled checks representing recorded Cash disbursements for the same period were examined by us, with the exception of those outstanding at December 31, 1928. We also examined vouchers, invoices, etc., for the year.

"Securities Owned, as stated, were examined by us on February 6, 1929, and are represented in the accompanying Balance Sheet at cost.

"Trial balance of the individual accounts evidenced the correctness of the amount stated as representing Accounts Receivable, but we did not correspond with the recorded debtors to further verify the correctness of the Society's records. It is our opinion that sufficient allowance has been made for doubtful accounts.

"Inventory, as stated, represents the cost value of bound volumes of the Society's publications, paper, cover stock, etc., on hand and at printers on December 31, 1928, as determined by the management.

"Under the caption of Other Assets are included advances to officers, employees and chapters, amounting to \$8,307.98.

"Permanent Assets, consisting of Furniture and Fixtures, are stated in this Balance Sheet at a nominal value of \$500.00, it being the Society's practice to charge off the excess over this amount at the close of each year.

"Deferred Assets consist of Prepaid Exposition and Convention Expenses and represent items, which, in our opinion, are proper charges against future operations of the Society.

"Provision has been made in the preparation of this Balance Sheet for all liabilities of the Society at December 31, 1928, disclosed by the records examined and information obtained by us.

"We also submit herewith a Statement of Income and Expense for the year ended December 31, 1928, prepared from the Society's records, on which Executive and Office Salaries have been prorated and charged to the various activities expense accounts. While we checked all of the vouchers for the year mentioned, we did not make a detailed audit of all the accounts represented in the aforementioned Statement of Income and Expense.

"Subject to the foregoing, WE HEREBY CERTIFY, that we have examined the books of account and record of the AMERICAN SOCIETY FOR STEEL TREATING—CLEVELAND, as of the close of business December 31, 1928, and that, in our opinion, based upon the records examined and information obtained by us, the accompanying Balance Sheet sets forth the financial position of the Society as of the date named."

(L. S.)

ERNST & ERNST, *Certified Public Accountants.*

BALANCE SHEET, DECEMBER 31, 1928

ASSETS			
CASH			
ON HAND			
Petty Cash Fund		\$	100.00
ON DEPOSIT			
Savings Accounts	\$ 30,214.88		
Commercial Account	2,981.02	33,195.90	\$ 33,295.90

SECURITIES (At Cost)			
U. S. Government Securities	\$ 27,689.70		
Other Securities	98,763.63	\$126,453.33	
Accrued Interest		2,333.33	128,786.66
ACCOUNTS RECEIVABLE			
Advertising	\$ 9,174.58		
Convention—1928	2,393.03		
Miscellaneous	1,216.12		
Convention—1927	59.72	\$ 12,843.45	
Less: Allowance for doubtful Accounts		583.39	12,260.06
INVENTORY (Certified by Management)			
Bound Volumes of "Transactions", Members' Pins, etc.			8,307.98
Other Assets			
Officers' and Employees' Accounts,			
Advances to Chapters, etc.			14,710.48
PERMANENT (Nominal Value)			
Office Furniture and Fixtures			500.00
DEFERRED			
Prepaid Western Metal and Machinery Exposition	\$ 5,842.99		
Prepaid 1929 Convention Expense	1,032.85		6,875.84
			\$204,736.92
LIABILITIES			
ACCOUNTS PAYABLE			
For Purchases, Expenses, etc.	\$ 3,904.79		
For Apportionment of Dues to Chapters	1,081.58		
Members' Credit Balances	332.86	\$ 5,319.23	
RESERVES			
For Conventions	\$ 20,000.00		
For Contingencies	20,000.00		
For H. M. Howe Medal Fund	5,000.00		
For General Index	500.00		45,500.00
DEFERRED INCOME			
Advance Receipts—Western Metal Show			22,605.00
SURPLUS			
Balance December 31, 1928			131,312.69
			\$204,736.92

INCOME AND EXPENSE STATEMENT YEAR ENDED DECEMBER 31, 1928

INCOME			
1928 CONVENTION—PHILADELPHIA			
Space Rentals	\$ 62,458.00		
Special Services	29,547.26		
Banquet	1,890.00		
Gate Receipts, Tickets and Passes	950.65		
Miscellaneous	633.92	\$ 95,479.83	
"TRANSACTIONS"—MONTHLY PUBLICATION			
Advertising	\$ 49,019.57		
Reprints	2,231.17		
Subscriptions	2,030.41		
Bindery	1,388.25		
Sales other than Subscriptions	889.71	\$ 55,559.11	
MEMBERSHIPS			
Membership Dues	\$ 59,684.84		
Sustaining Exhibit Membership	5,575.00	\$ 65,259.84	
		25,351.17	39,908.67
Extension Division			12,875.00
DATA SHEETS			
Book Advertising	\$ 7,025.00		
Sheets, Binders and Books	2,556.65		9,581.65
Interest Earned			7,184.14
John F. Keller Book			3,917.03
Books			3,346.07
E. D. Campbell Memorial Lecture			1,175.00
Discount Earned			911.57
Credit Balances Absorbed			465.17

May

1929

NEWS OF THE SOCIETY

891

Recoveries on Accounts previously charged off	344.60
Miscellaneous	173.79

TOTAL INCOME \$230,921.63

EXPENSE

AS SHOWN BY EXHIBIT

1928 Convention—Philadelphia	\$ 84,031.82
"Transactions"—Monthly Publication	44,005.92
Extension Division	12,076.18
Data Sheets	12,206.33
Secretary's Office	16,277.20
Treasurer's Office	5,948.40
President's Expense	241.87
General Expense	14,600.58
Recommended Practice	3,560.58
Directors' Expense	2,289.80
National Committees	1,119.53
John F. Keller Book	604.74
Semi-Annual Meeting	512.07
	\$197,475.02

Books Purchased for Resale	2,851.86
E. D. Campbell Memorial Lecture Expense	1,932.38
Reprints Purchased for Resale	1,807.60
Support of Chapters	794.38
Bindery Purchases for Resale	790.86
Books Purchased for Library	370.86
Accounts Receivable Charged off	314.18
Dr. Hatfield Book-Paper and Cover Stock	70.00
Pencils, Pins and Buttons	51.39
H. M. Howe Medal Fund Expense	50.00

TOTAL EXPENSE 206,508.53

NET PROFIT \$ 24,413.10

UNAUDITED PROFIT AND LOSS STATEMENT
AMERICAN SOCIETY for STEEL TREATING
For the period from January 1 to March 31, 1929

INCOME

Membership Dues	\$ 24,098.37		
Sustaining Exhibit Membership	3,125.00	\$ 27,223.37	
Less—Apportionment of Dues to chapters		10,653.30	\$ 16,570.07
Transactions—Advertising	\$ 10,234.61		
Subscriptions	1,134.72		
Sales	292.15		
Reprints	529.17		
Bindery	456.50		\$ 12,647.15
Books Purchased			422.30
General Index			8.40
Books Published			1,669.50
Data Sheets, Binders and Books			737.95
Extension Division			1,065.00
Western Metal Show—Special Service		3,520.24	
Space Rentals		32,864.68	
Other Income		3,788.75	40,173.67
Interest Earned			296.80
Discount Earned			154.46
Sundry Income			57.00
1929 Convention Advance Receipts	\$ 9,553.50		
TOTAL INCOME			\$ 73,802.30

EXPENSE

Support of Chapters		\$ 213.13
Transactions		9,069.53
Reprints		307.72
Bindery		85.23
Books Purchased—For Library		63.50
For Resale		222.18
Books Published		986.57
Data Sheets, Binders and Books		901.92
Extension Division		1,196.37
Western Metal Show—Special Service	\$ 5,460.74	
Other Expenses	30,271.70	35,732.44
National Committees—Recommended Practice	\$ 793.09	
Publications	70.75	863.84

Directors		382.37
President's Office		10.00
Treasurer's Office		1,267.16
Secretary's Office		4,931.63
General Expense		3,025.88
1929 Convention Deferred Expense	\$ 4,441.80	
TOTAL EXPENSE		\$ 59,259.47
EXCESS INCOME OVER EXPENSE.....		\$ 14,542.83

BALANCE SHEET

As of March 31, 1929

ASSETS		
Petty Cash Fund	\$ 270.20	
Cleveland Trust Company (Commercial Account).....	21,597.88	
Savings Accounts	25,914.88	\$ 47,782.96
U. S. Government Bonds	27,689.70	
Other Securities	112,632.38	
Accrued Interest	693.61	141,015.69
Accounts Receivable	5,544.65	
Less Allowance for Doubtful Accounts	581.89	4,962.76
Inventory		8,307.98
Travel Advances		1,428.64
Office Furniture and Fixtures		579.50
1929 Convention Deferred Expense		4,441.80
TOTAL ASSETS		\$208,519.33
LIABILITIES, RESERVES AND SURPLUS		
Accounts Payable	\$ 8,021.10	
Reserves	45,500.00	
1929 Convention Advance Receipts	9,553.50	
SURPLUS		
January 1, 1929	\$131,312.69	
Excess Income over Expense during period from January 1 to March 31, 1929	14,542.83	
Less	\$145,855.52	
Adjustments for past periods	410.79	145,444.73
TOTAL LIABILITIES, RESERVES AND SURPLUS.....		\$208,519.33

The officers and directors of the American Society for Steel Treating regret to note the death of Henry Le Chatelier of Paris, France, honorary member of the society since 1922. The scientific work and contributions of Professor Le Chatelier are too numerous to be recorded here. The far-reaching importance of his thermoelectric couple is well known to those of the steel treating fraternity and its value can hardly be overestimated. Professor Le Chatelier was a member and officer of many technical societies. He was a member of the Institute and Inspector General of Mines (retired).

A paper entitled "The Theory of Heat" written by Professor Le Chatelier was published in the April 1928 issue of TRANSACTIONS.

We regret to record the death of Charles E. Carpenter, Saturday, April 6, 1929, at Miami Beach, Florida. Mr. Carpenter was a sustaining member of the Philadelphia Chapter and a loyal supporter of the society. He is known for his writings on non-technical subjects in the "Houghton Line" published by E. F. Houghton and Company, of which Mr. Carpenter was president.

May

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